Submission date: 03-Aug-2009
Submission date of revisions: 14-Feb-2010 Final decision date: 19-Mar-2010
Coordinating Editor: Dr. Janet Ohmann

Taxonomic identification of Amazonian tree crowns from aerial photography

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Abstract

Question: To what extent can aerial photography be used for taxonomic identification of Amazonian tree crowns?

Objective: To investigate whether a combination of dichotomous keys and a web-based interface is a suitable approach to identify tree crowns.

Location: The fieldwork was conducted at Tiputini Biodiversity Station located in the Amazon, eastern Ecuador.

Methods: High-resolution imagery was taken from an airplane flying at a low altitude (600 m) above the ground. Imagery of the observable upper layer of the tree crowns was used for the analysis. Dichotomous identification keys for different types of crowns were produced and tested. The identification keys were designed to be web-based interactive, using Google Earth as the main online platform. The taxa analysed were *Iriartea*, *Astrocaryum*, *Inga*, *Parkia*, *Cecropia*, *Pourouma*, *Guarea*, *Otoba*, Lauraceae and *Pouteria*.

Results: This paper demonstrates that a combination of photo imagery, dichotomous keys and a web-based interface can be useful for the taxonomic identification of Amazonian trees based on their crown characteristics. The keys tested with an overall identification accuracy of over 50% for five of the ten taxa with three of them showing accuracy greater than 70% (*Iriartea*, *Astrocaryum* and *Cecropia)*.

Conclusions: The application of dichotomous keys and a web-based interface provides a new methodological approach for taxonomic identification of various Amazonian tree crowns. Overall, the study showed that crowns with a medium rough texture are less reliably identified than crowns with smoother or well-defined surfaces.

Key words*:* Dichotomous keys; web-based interface; trees; photo interpretation; Tiputini Biodiversity Station; Amazon Forest; Ecuador

Nomenclature: Gentry (1993)

Introduction

Aerial photographs have been commonly used for classification of different types of forests (Myers 1982a; Murtha, 1972; Sayn-Wittgenstein, 1961; Paine & Kiser 2003; Wear et al, 1966). However, the application of airborne imagery for taxonomic identification of individual tree crowns is poorly explored. The Amazon forest is an extremely diverse environment but tree diversity is diminishing every day, caused in part by large scale forest degradation (Betts et al. 2008). Mapping trees using high-resolution imagery might allow taxonomists or ecologists to rapidly locate key regions of higher tree diversity. In the study of forests inventories, there is a need to develop new tree identification techniques that can be used as tools for rapid tree taxonomic or ecological assessment of large areas. In this paper, we investigate the capabilities of combining photo interpretation, dichotomous identification keys and a web-based interface to map trees by the appearance of the crowns.

High-resolution satellite imagery for biodiversity assessment has generated high expectations but is still in the early stages of development (Nagendra & Rocchini 2008). Temperate regions provide the most advanced information on ecological research and forest biodiversity. Meanwhile the tropics offer a challenge due to a more complex canopy structure and a greater number of species (Nagendra 2001). Since the early 1970s until mid-1980s, significant progress was made in demonstrating the potential application of aerial photographs for tropical tree identification. In rain forests located in Surinam, Sayn-Wittgenstein (1978) found that “species could be identified with a reasonable degree of success”. Subsequently, Myers (1982 b) explored means of describing upper canopy tree crowns in northern Queensland rain forests in Australia, developing terminologies based on structural characteristics of internal crown parts using stereoscopy of stereo images. These photographs were used to identify crown features by the eye from different tree species, located in 0.5-ha ground plots and adjacent plots with a total training set area of six ha. An overall accuracy of 75 % was obtained for 24 species and 80-100 % for the most important commercial timber species. He also reported that 73 % of the 1100 different trees interpreted were correctly identified.

From the 1990's until now, significant advances in aerial photo survey techniques have been made through the use of better quality photographs that have finer spatial resolution and cover larger areas of forest (Brandtberg & Walter 1998; Chumbey et al 2006; Culvernor 2002; Fenshman et al 2002; Gougeon 1995; Leckie et al 2003; Pouliot 2002). Trichon (2001) applied stereoscopic techniques that allowed her to analyse the upper level of the crowns using aerial photographic prints at a scale of 1:600 (equivalent to 0.3-m spatial resolution). The author developed a typology with detailed classification criteria for individual upper crown layers in French Guyana for twelve tree categories. The visual interpretation of the photographs was very clear for recognising some structures within the crown. Trichon & Julien (2006) tested the accuracy of Trichon's (2001) method, obtaining 87% overall tree species identification accuracy using aerial photography in French Guyana. They used 5-ha plots for the training set and 16.25-ha for the validation sets. Their terminology was based on crown structural criteria such as shape and texture.

The published literature about aerial identification of trees in tropical rainforests contributes significantly to the remote identification of crown features (Cuervo 2002; Erikson 2004; Myers 1982 a; Myers 1982 b; Sayn - Wittgenstein 1978; Sayn - Wittgenstein et al. 1978; Trichon 2001; Trichon & Julien 2006; Verheyden et al. 2002). Despite a reasonable body of literature on aerial mapping of trees in tropical rainforests, few studies have been published on the Amazon region (Asner et al. 2002; González-Orozco & Mulligan 2009; Palace et al. 2008). As a consequence, there is still a knowledge gap in the use of high-resolution aerial photographs for taxonomic identification of tree crowns in the Amazonian rainforests.

Mapping tree canopies with remote sensing techniques in tropical rainforests is a difficult task because it does not provide enough spatial resolution to distinguish the taxonomic characters that botanists usually apply for ground-based taxonomic identification. We present a new approach to map tree species in tropical rainforests. Our method can complement traditional taxonomy and could also improve monitoring of tropical forest diversity from the air. A combination of high-resolution aerial photographs, dichotomous keys, and a web-based interface was used for the characterisation and identification of tree crowns. Our objectives were to: (a) understand and describe crown properties suitable for taxonomic identification for 10 taxa; (b) classify the crown properties in a taxonomical manner using a dichotomous key; and (c) validate the identification accuracy of the keys through users via a web-based interface.

Methods

Study area

The fieldwork was conducted at Tiputini Biodiversity Station (TBS) in the Amazonian region of western Ecuador, Orellana Province (Figure 1). TBS is located on the equator (0° 37’ S - 76° 10’ W), next to Yasuni National Park, which is a UNESCO biosphere reserve (Myers et al. 2000). The Yasuni region has an average rainfall of 3200 mm/yr $^{-1}$ and an average annual temperature of 15° C. Ninety percent of the land area is *terra firme* forest, with 10% swamp and riverbank forest coverage (Pitman 2000).

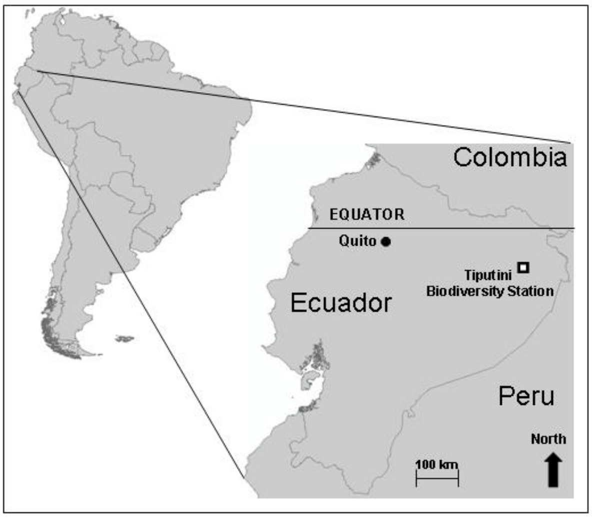


Fig. 1. Location of the study area at Tiputini Biodiversity Station (TBS) in Ecuador, South America.

Methodological strategy

The methodology consisted of five stages: (a) image acquisition and control; (b) collection of ground-based data; (c) identification of crowns in images; and (d) development of a taxonomic key containing the crown images; and (e) validation of the keys through volunteers.

Image acquisition

Aerial photography was taken using a Kodak DCS420A digital camera. The camera was mounted vertically in the bottom of the aircraft, level with an open window. Photos were taken at the elevation of 600 m above the ground, providing images with a pixel size of 21.4 cm and a spatial coverage of 524m x 348m. These photos were used for identification of the crowns and were included in the taxonomic keys. For georeferencing purposes, photos were also taken at 1200 m above ground. Figure 2 shows the imagery for 180 ha, comprised of individual high-resolution aerial photograph tiles.

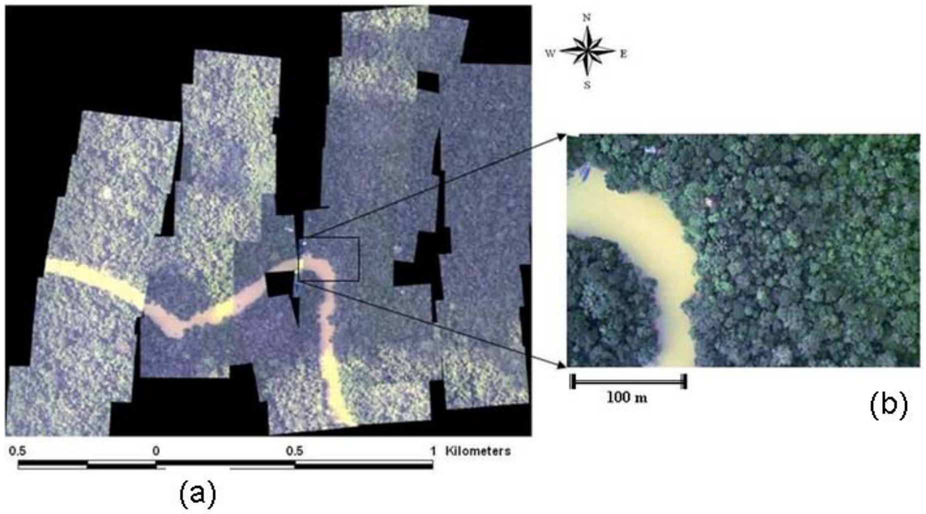


Fig. 2. TBS aerial view (a) and high-resolution photography tile (b).

Low-elevation aerial photography, which produces high-resolution data, is not routinely used in the Amazon basin because cloud-free days are rare. Due to limitations in fuel capacity and high winds which caused unexpected deviation from predetermined flight routes, it was only possible to cover 80 % of the TBS reserve area by airplane. The time of the day the images were acquired was between 12:00 and 13:00 h. The sky was about 80 % clear, with just a few isolated clouds. Both high-quality images and distorted imagery was collected. The set of images used for our analysis were those that were not blurred and did not contain irregularities such as shadows and bright illumination. Gyroscopic instrumentation was not used and therefore crowns in these images were geometrically distorted. In order to reduce the motion effect and improve the image quality, a motion compensation frame was used. The camera was calibrated to determine the relationship between the distance of the sensor from the target, the spatial resolution and spatial coverage. Images were also taken from a helium balloon below 200 m above the ground. This complementary technique was used to obtain hyper resolution-images of the crowns and establish control points in the observable features of the landscape. The helium balloon images were used as a reference for creating a more robust control point strategy. The combination of the hyper-resolution images (approximately 6 cm pixel size) with the low-elevation airborne imagery was used to improve accuracy in our methodology.

Image control and georeferencing

The aerial photos were georeferenced using GPS data through an iterative approach, using the 1200-m imagery (Jarvis 2005). First, in-flight GPS data and camera characteristics derived from the calibration were used to georeference the images. The GPS height was used to calculate the spatial coverage and geographic points of the corner points, which were subsequently used as control points in the georeferencing.

In order to secure the spatial geographical location accuracy, common features were identified for control points, using at least 10 points per image. Identifiable features on the crudely georeferenced image closest to the TBS accommodation cabins were selected. The easiest and most observable features to identify were buildings. Logs and outcroppings in the

Tiputini riverbank were also easily identifiable in the images and in the field. On land and away from buildings it was more difficult; only features such as large gaps, flowering trees, large leafless trees and some especially prominent palms could be identified. These features were visited in the field and the approximate coordinates of each identified feature were entered into a Garmin12 GPS unit. Once the precise point was found, the Trimble ProXL GPS unit was left for at least 10 minutes in order to calculate a geographic position. For each image, features located in each corner and a central point was used to establish at least five GPS points.

This “dispersive” method was used to first to georefence all 1200-m images. The root mean square was approximately 3-5 pixels (equivalent to 1-2 m). Once the 1200-m images had been georeferenced, they were mosaicked (33 % overlap with the first image) to form a single image of the study site. This mosaic was then used as a base map with which to georeference the 600 m imagery with ERDAS Imagine software (Alexandria, VA, US), using bi-linear interpolation of the GPS points. The helium balloon images were more easily georefenced due to the clarity in the photos. Reference features were also located on the ground, and ERDAS Imagine was used to georeference only the high-quality images. The approximate accuracy of the georeferencing using this method was 1 m.

Collection of tree data

Tree data were collected using image-centered selection and ground-centered methods.

Image-centered selection

Individual crowns were selected by hand from the aerial photographs. Different crown types were chosen in different locations at TBS. Elevation, upslope area indicative of soil wetness, proximity to rivers and slope were the biophysical criteria used for selecting samples. The image-centered sampling strategy ensured that selected crowns represented a combination of these environmental variables. Each visually selected crown was marked as a collection point. When visiting the field, crowns selected from the imagery were located individually with the aid of a GPS. Most of the crowns sampled and identified taxonomically during image-centered sampling belonged to six dominant families. This stage of sampling did not achieve the minimum statistical sample of sixty crowns per taxa. Therefore, a second data collection was required.

Ground-centered collection

The purpose of ground-centered collection was to ensure that a minimum of 60 crowns were ground-sampled in each genus and family. We first located a conspicuous reference point such as a tall tree to be used as the starting collection position. Once the collection point was located on the ground with respect to the imagery, surrounding tree crowns in different directions were GPS-located, mapped and identified taxonomically. In this way, the initial database was enlarged with reliable samples that were taxonomically easy to recognise in the field and on the image.

Using these two approaches, a total of 804 crowns were located, identified and mapped during three expeditions to TBS between September 2005 and June 2006. From the 804 crowns, only 600 were included in the final analysis because the other 204 were not from the botanical families analysed in this study. 300 crowns were collected using image-centered selection and 300 using the ground-centered method.

Taxa studied

Individual crowns representing ten taxa were chosen for analysis (Figure 3). These taxa were chosen because they contain a representative range of crown structural characteristics, they are taxonomically easy to identify in ground surveys and represent families that are distinctive of the Amazonian flora.

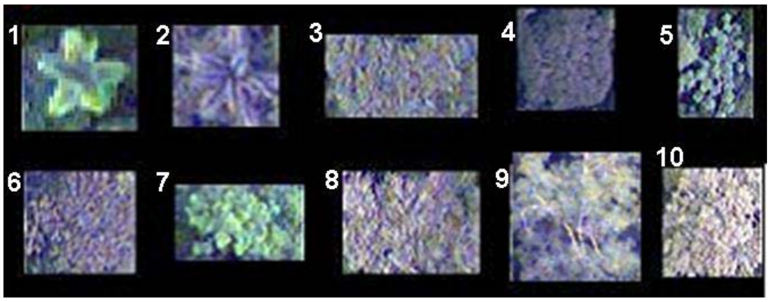


Fig. 3. Maximum-resolution aerial photo of the ten taxa mapped across TBS. (1) Arecaceae- *Iriartea deltoidea*; (2) Arecaceae- *Astrocaryum chambira*; (3) Fabaceae- *Inga*; (4) Fabaceae- *Parkia;* (5) Moraceae- *Cecropia;* (6) Moraceae- *Pourouma;* (7) Meliaceae- *Guarea*; (8) Myristicaceae- *Otoba*; (9) Lauraceae; (10) Sapotaceae- *Pouteria*

Development of a taxonomic key

Description and assignment of crown properties

We modified Trichon's crown criteria (2001) to correspond to the Amazonian crown types, due to differences in structural configuration with crown types of the Guyana flora. The glossary (Table 1) defines the crown characteristics criteria, with a total of three crown properties and 12 sub-classes. Each of the studied taxa was described according to the crown characteristics (Table 1 and Figure 4). Crown properties were assigned to each sample tree according to the representative crown properties (Figure 4).

Crown properties	**Descriptor/Class**	**Description**
Crown type	Single	A crown with a well-defined centre or without clear division within the crown
	Multiple	A crown that has two or more divisions within the crown with each component resembling an individual crown
Crown shape	Flat	An almost horizontal shape
	Rounded	A defined surface curvature
Foliage texture	Smooth	Texture of the upper crown surface looks constant
	Rough	Texture of the upper crown surface looks irregular
	Mottled	The upper crown surface is irregular but not clumped
	Grainy	Repetition of small leaves
	Granular	Repetition of larger particles that are like clumps; these particles can be clusters of leaves or crownlets
	Smoky	Opaque or light foliage with leaves that are not compacted
	Spotted	Foliage is light and leaves are separated, appearing like large spots in the crowns.

Table 1. Properties used for describing the TBS tree crowns. Adapted from Trichon (2001).

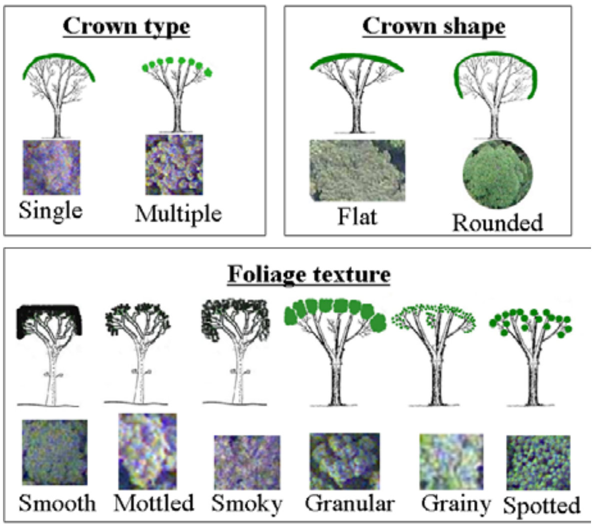


Fig. 4. Photographs illustrating the most common crown properties.

Production of the identification key

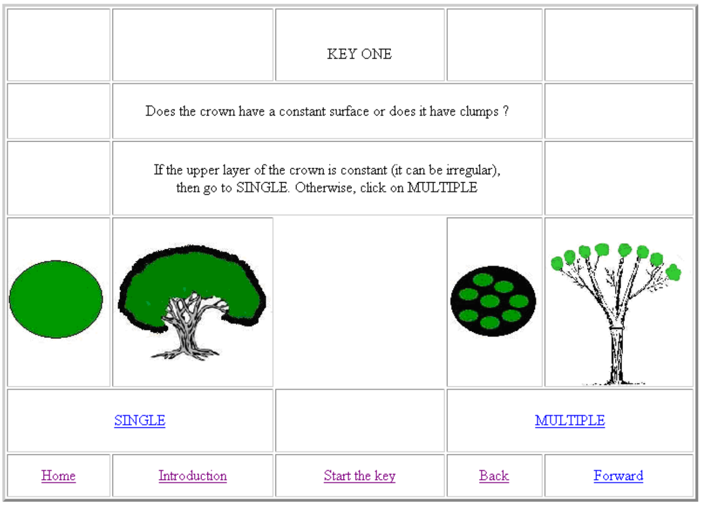
The assigned crown properties were combined with the taxonomic identification for each taxa and used to develop a set of dichotomous keys for the whole dataset as described in Figure 5. These identification keys consisted of comparing two contrasting characters using a discrimination task, resulting in the identification of the tree.

A	Tree crown rounded, then go to B	
A'	Tree crown palmed, then go to C	
B	Crown type single, then go to D	
B'	Crown type multiple, then go to E	
C	Star shape (leaves arranged planar)… … … …	ARECACEAE *Iriartea*
C'	Rosette shape (leaves arranged spatial)… … .	ARECACEAE *Astrocaryum*
D	Flat shape (rough texture)… … … … … … … .	FABACEAE *Inga*
D'	Rounded shape (smooth texture)… … …	FABACEAE *Parkia*
E	Crown regular, then go to F	
E'	Crown clumping, then go to G	
F	Grainy texture… … … … … … … … … … … …	MORACEAE *Pourouma*
F'	Spotted texture… … … … … … … … … … … ..	MORACEAE *Cecropia*
G	Few and well formed clumps, then go to H	
G'	Many irregular clumps, then go to I	
H	Small clumps… … … … … … … … … … … … .	LAURACEAE
H'	Large clumps… … … … … … … … … … … … .	SAPOTACEAE *Pouteria*
I	Smoky texture… … … … … … … … … … … …	MYRISTICACEAE *Otoba*
I'	Mottled texture… … … … … … … … … … … .	MELIACEAE *Guarea*

Fig. 5. Dichotomous key illustrating the crown taxonomic identification of the studied taxa

Validation of the key

Using the identification key, two web-based identification keys were developed (Figure 6). The reason for this was to determine which key was more accurate for the identification of the 10 tree crowns. Key two differs from key one as it contains an image of the crown in addition to the drawing. Both keys were embedded in the TBS photo mosaic displayed in Google Earth (accessible at www.ambiotek.com/treeid). Users were directed to go to the website and using both keys, identify the ten taxa. One hundred volunteers served as key users, the majority having experience in plant ecology, environmental studies, remote sensing and physical geography. The crowns to be identified were marked red on the mosaic. By clicking on the mark, the user could display the keys, which include a set of dichotomous questions. Each of the online keys allows the user to identify the crown in the images with respect to the online description.



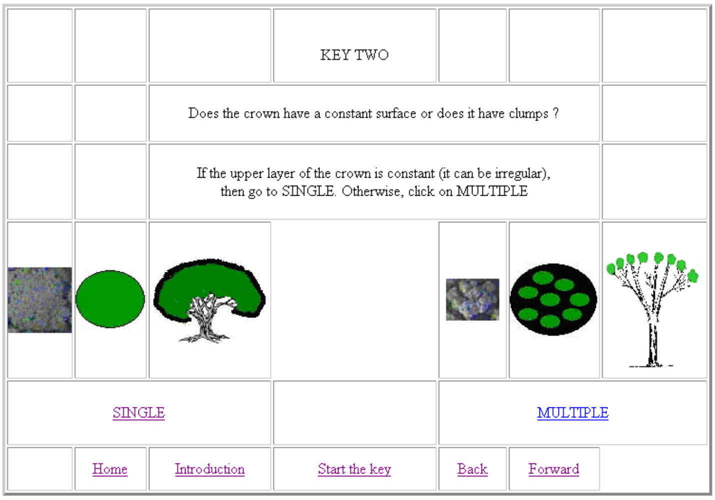


Fig. 6. Examples of questions in key one and key two found on a web-based interface.

Data analysis

The responses were automatically stored in a database. The online key results were used to calculate the percentage of correct identifications and the most common errors. Commission errors were accounted in order to identify which properties were consistently incorrectly identified by users. The commission errors were considered to be those that did not match the correct answer and therefore were confused with other taxa. Omission errors were not accounted for in the results.

The overall identification accuracy (A) was calculated as follows:

$$A = n / T, \text{ where}$$

n = Number of crowns correctly identified per taxa; and

T = Total Number of crowns per taxa

Results

Identification accuracy

Identification accuracy between 70 % and 95 % was obtained using identification key two for *Iriartea deltoidea, Astrocaryum* and *Cecropia*, and over 50 % using identification key one (Figure 7). From the ten taxa evaluated only five presented accuracy over 50 % (*I. deltoidea, Astrocaryum chambira, Cecropia, Inga* and *Parkia*). Only *I. deltoidea, A. chambira* and *Cecropia* have a taxonomic identification consistently over 50 % using both identification keys one and two. Accuracy was higher with key two, except for *Inga* which has the easiest crown type to identify apart from *I. deltoidea* and *A. chambira*. Because of *Inga*'s flat upper surface in the majority of the dataset, their identification accuracy was higher than other crown types with a more complex structure.

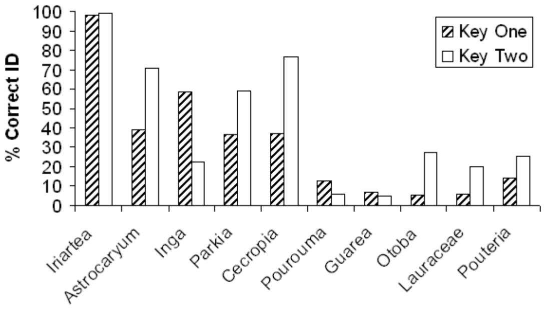


Fig. 7. A comparison of overall identification accuracy for key one and two for ten Amazonian tree taxa

Iriartea and *Astrocaryum*, belonging to the Arecaceae family, are abundant in the canopy at TBS. The particular palm-type crown is easily identified in comparison to the rest of the crowns in other tree families. *Iriartea deltoidea* can be recognised for having a well-defined star-shaped crown. In contrast, *A. chambira* has a larger and more open crown than *I. deltoidea*, with an appearance like an open rosette.

The genus *Cecropia* is the second most successfully identified after palms. It belongs to the Moraceae family, which is commonly found at the canopy and sub-canopy strata in the Amazonian forest. *Cecropia* has a candelabra-like system and terminal clumps of foliage that, when observed from above, appears like dots.

Taxa with accuracy over 50 % but less than 70 % (*Inga* and *Parkia).*

Inga and *Parkia* belong to the Fabaceae family.. *Inga* presents a single crown type characterised by a flat-shaped upper crown with a rough texture and evenly distributed foliage. In contrast, *Parkia*, has a single round shaped crown with an irregular texture and a smooth appearance. *Parkia* can be potentially confused with *Pourouma* but the latter has a texture that looks like small grainy dots (representing individual leaves) that are located close together while *Parkia* has a rougher texture.

Guarea, *Otoba*, Lauraceae and *Pouteria* presented a high number of commission errors compared to the rest of the taxa. Key two produced more accurate results than key one, as can be seen in Table 2, as it had a lower rate of incorrectly identified taxa (562 for key 1 versus 469 for key 2). In other words, the identification error decreased when aerial pictures of the crowns were included in the key display. The best identification results were obtained for *I. delotidea* with only two errors in key one and one error in key two. On the other hand, a higher number of identification errors with both keys were obtained for *Pourouma* and *Guarea*.

TAXA **/KEYS**	**KEY ONE**	**KEY TWO**
Iriartea	2	1
Astrocaryum	62	28
Inga	40	60
Parkia	44	30
Cecropia	48	12
Pourouma	86	76
Guarea	66	79
Otoba	84	58
Lauraceae	72	62
Pouteria	58	63
TOTAL PER KEY	562	469

Table 2. Number of commission errors per taxa using identification key one and key two

Discussion

The use of dichotomous keys combined with the application of a web interface makes our research original. Dichotomous keys have been used extensively in taxonomic studies for at least a century. They have been proven to be effective identification tools for a large variety of plant groups. The main advantage of using a dichotomous approach is it allows identification of the most appropriate taxonomic criteria in a simple, hierarchical and systematic manner. In some cases a dichotomous key has not provided a high level of accuracy in species identification. Myers (1982 a) states that Sayn-Wittgenstein et al. (1978) "attempt to construct a dichotomous key for species identification in Surinam was unsuccessful". Regardless of the limitations, we satisfactorily show that this method was successful in our research.

The use of Google Earth® enabled the interaction between the users and the online dichotomous key. For the first time, this procedure allowed users to observe, identify and validate identification accuracy of tree crowns through an html format integrated with the high-resolution aerial photographs taken over the Amazon canopy. This case study contributes to the vegetation literature and specifically to the new web-based research called CyberTaxonomy. Recently, the European Distributed Institute of Taxonomy (EDIT) discussed the introduction of the term CyberTaxonomy, which is defined as "a taxonomic work process that involves the use of standardised electronic tools to access information (databases, e-publications) and/or to generate knowledge bases (identification keys)" (Ebach 2007).

There are several reasons for a high level of inaccuracy in identifying tree crowns. Lack of finer spatial resolution can explain low identification success of some taxa. For this reason, we used fine-resolution images (21-cm pixels) for the crown identification process. The structural complexity of different crowns (variability between species) as well as the difficulty of applying objective crown classification criteria may also result in errors in identification of crown properties. Identification errors can be expected to be higher if volunteers are not familiar with the criteria before using the keys. Another potential contributor is crown geometric distortions created by imagery inconsistencies in aerial photographic acquisition. Lastly, problematic reasons related to the image quality due to the camera and view angle (Howard, 1970), spatial resolution (Wulder 1998; Verheyden et al. 2002) light conditions (Hu et al. 2000) and spatial geometry (King 1998) can cause identification errors. The angle of the image with respect to the ground causes image geometry distortion. When the image axis is not completely vertical to the surface, it produces a deformation of the object. The excessive brightness (light reflectance) on the canopy surface complicates the recognition of the textural properties by eye. More specifically, high lateral light intensity creates the shadow effects, which means less contrast and therefore more difficulty in identifying the edges of the object, which may affect the visual judgment of crowns.

Crowns with a more complex and irregular texture produce lower overall accuracy. The most reliably identified crowns tend to be more defined in appearance, as was demonstrated in our results for the palm trees, which have very distinctive features and were identified with few accuracy errors. This may be explained by the visual texture recognition theory, which suggests that “structures with discernible elements can be segregated more easily than patterns in which the same texture elements are more widely spaced” (Nothdurft 1985). The theory of the perception of textures states that “textures composed of well-defined texels (e.g., bricks) may be more accurate than for textures with less well defined texels” (e.g., splatter patterns) (Kraft & Winnick 1967; Velisavljevic & Elder 2006).

The topographic variation of the landscape is another factor that complicates the aerial identification of the crowns. Particularly, the variation in slope is not always obvious for the human eye due to the two-dimensionality of the surface in airborne imagery. This effect creates a dual canopy surface that confuses the visual appearance of the object, in this case the crown surface, with neighbouring features.

Interpretation of high-resolution aerial photographs is an interesting prospect for new generations of tropical botanists/taxonomists and ecologists. Specifically, this technology could be used as a complementary method to produce rapid surveys of trees at community levels. It could also be used as a complementary sampling strategy for highly diverse and remotel forested regions. It may also be used as one element of a predictive habitat distribution model in tropical ecology studies. In our study we demonstrated that some of the tree taxa can be remotely mapped in a reliable manner. Our approach could be applied more widely if used with a new generation of hyper-resolution satellites such as GeoEye or QuickBird.

Our research suggests that semi-objective tree crown identification can be inconsistent. A combination of automatic tree crown mapping approaches (Asner et al. 2007, 2008;

Holmgren et al. 2008; Lucas et al. 2008) and human understanding of crown characteristics can improve the accuracy. Image analysis software based on object classification may provide greater identification accuracy and less subjective classification. Following this logic, linking aerial photographic data with taxonomic knowledge and new object-oriented classification technologies may facilitate a new approach called “aerial taxonomy”.

Conclusions

Our research aims to bridge the gap between traditional plant identification methods (collection and herborization) and the use of high-resolution photographs for rapid assessment of the composition of tropical rainforest flora. Traditional methods are the most accurate but cannot be applied rapidly across large areas in remote regions. Therefore, complementary techniques to identify canopy tree crowns (not necessarily species) using photographs are necessary. We demonstrated that a combination of dichotomous keys which include aerial photographs and web-interface tools can be a useful approach to identify taxonomically some canopy taxa. Although results are not consistent for all kinds of tree crowns, the technique is a potential tool for forest monitoring and rough floristic survey over large areas.

Our results lead to the following conclusions:

- Crown characteristics visually identified from aerial photographs combined with dichotomous keys and a web-based interface may be a suitable tool for operational purposes but should be combined with an automatic classification approach.

- The accuracy of the identification averaged 70 % for five of the ten taxa studied. The accuracy generally improved when example images of each tree species was included in the key. The method was well-suited to identify palms and *Cecropia* trees, with an overall identification accuracy of more than 70 %. We obtained an overall accuracy between 50-70 % for *Inga* and *Parkia*. The rest of the taxa scored an identification accuracy of lower than 50 %.
- Aerial identification of Amazonian trees using photo-interpretation was less accurate when the upper layer of the crown had a poorly defined texture, for example, crowns with patterns that contain an irregular surface and low degree of clumpiness.
- Taxa that share common crown properties were the hardest to distinguish using aerial photography. In the area studied, common crown features that were most confused were single crowns with foliage textures that vary from mottled to smoky types. *Guarea* and *Pouteria* were the most difficult genera to distinguish using the key.
- More research needs to be undertaken, exploring the connection between empirical tree crown identification methods (as presented in this paper), multispectral satellites, and automatic object-oriented classification methods.

Acknowledgments. The authors wish to acknowledge funding provided by Programme Alban (European Union Programme of High level Scholarships for Latin America, Award nº E03D26669CO), WWF (Russell E. Train fellowship, Education for Nature Program), Royal Geographical Society fieldwork grant, Rufford Small Grant and Herb project fieldwork support (King's College London). I would also like to acknowledge Dr. Greg S. Biging for the valuable comments provided in reviewing this paper. Special thanks to the Universidad San Francisco de Quito and particularly to the TBS staff that assisted in the collection of data and logistic support at TBS, including Constanza, Jaime, David, Kelly and Fabian Nenquimo.

The authors also wish to thank the following institutions: Department of Geography at King's College London, Tiputini Biodiversity Station TBS, Universidad Catolica-Quito-, Universidad San Francisco de Quito, Centro Internacional de Agricultura Tropical-CIAT, Museo de Historia Natural in Popayán, Universidad del Cauca, and three reviewers for valuable comments

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