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# Detection and characterization of Sri Lankan mixed dipterocarp forest structure across physiographic gradients and its effects from logging

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### Abstract

The ability to document change in forest structure from remote sensing images would greatly assist in monitoring and conservation efforts. This study compared the spatial distribution of individuals across physiographic gradients in an attempt to characterize differences in stand structure resulting from past disturbance regimes, using field and remote sensing data. Past selective logging has led to major impacts on mixed dipterocarp forests of Sri Lanka, one of the most biologically diverse regions in the world. Using crown width measurements taken directly from Google Earth®, stand structure was characterized for different site types through comparison and analysis of biophysical measurements obtained from field sampling. In the study area, a high correlation was found between remote crown spread measurements and physiographic position. Additionally, remote crown spread measurements were found to correlate with field measured DBH and height measurements. It was concluded that accurate predictions among disturbed and undisturbed sites could not be obtained through crown spread measurements alone.


## Introduction

Understanding the nature of forest canopy structure and its ability to recover in relation to past disturbance is a critical attribute for development and implementation of conservation strategies. In the past, a major impact on the mixed dipterocarp forest of Southeast Asia has been selective logging. A better understanding of the effects of selective logging on forest dynamics could greatly benefit efforts for future land management in planning, conservation, and restoration. Moreover, while many studies have utilized remote sensing and Geographic Information Systems (GIS) for land classification worldwide, few have focused on Sri Lanka (Rebelo et al., 2000; Dahbouh-Guebas et al., 2002; Miura, 2006; Lindström, et al., 2012; Perera, 2013), and fewer have addressed anthropogenic disturbance in Sri Lanka (Perera, 2001; Madurapperuma and Kuruppuarachchi, 2014). With increased public availability of aerial data through Google Earth and GIS, development of cheap and robust methodologies would greatly empower conservationists of the region and aid in restoration strategies.

There exist numerous examples where GIS and remote sensing have been used to build time-lapsed chronologies of disturbance regimes, including mountain bark beetle (Masek, et al., 2008), human disturbance of buffer zones (Lindstr:om, et al., 2012; Madurapperuma, 2014), clear-cut logging and wildfires in North America (Cohen et al., 2002; 2010), and landslides, volcanoes, flooding, and coastal inundation in various regions (Tralli

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et al., 2005; De LaVille et al., 2002). While many of these studies focused on effects at the landscape level, none have integrated remote sensing, GIS, and aerial photography to observe the effects of forest canopy disturbance at a local scale. This study attempted to use remote sensing, GIS, and Google Earth® for characterization of the forest canopy across physiographic gradients to reveal the effects of selective logging.

Sri Lanka is a tropical island located off the southeastern coast of India. Vegetation types differ across the country depending on climatic variability; both tropical wet forests and tropical dry forests occur on the island. The island contains several areas recognized as the most biologically diverse and important regions of the world. One of which is the Sinharaja Forest Reserve, the last extensive vestige of primary wet forest and home to over 830 endemic species (UNESCO, 2015). Changes in land use since colonial times have increasingly pressured these natural ecosystems resulting in increased conversion and degradation of native forest. Of the total 65,610 $km^2$ of land in Sri Lanka, the total forested area decreased from 23,350 $km^2$ to 19,330 $km^2$ between 1990 and 2005 (FAO, 2006).

Since 1900, the population density of Sri Lanka has increased more than five-fold from 54 persons $km^{-2}$ to 269 persons $km^{-2}$, while forest cover has decreased from 4.5 million ha to 1.6 million ha (IUCN, 2010). Further, the Forestry Sector Master Plan has estimated that by 2020 closed canopy forest will decline to 17% of the country's land area down from 70% of the land area at the turn of the $20^{th}$ century (IUCN, 2010). As of 2001, only 15% of the remaining mixed dipterocarp forest in the southwest of the island remains (Ashton, et al., 2001), an important forest type, which is home to the majority of endemic flora and fauna in Sri Lanka.

According to Ashton et al., (2001), disturbance regimes vary in type and severity in the mixed dipterocarp forest and result in tree species having different topographic affinities (Gunatilleke et al., 2006). Canopy crown size, degree of homogeneity and compactness can be observed to change across topographic gradients presumably in response to underlying drivers in soils, hydrology and mesoscale exposure to differences in wind, radiation and temperature (Ediriweera et al., 2008). Research is now needed to quantitatively link field measurements of crown and tree structure to changes in crown size and structure of mixed dipterocarp forest through remote sensing, GIS, or Google Earth®.

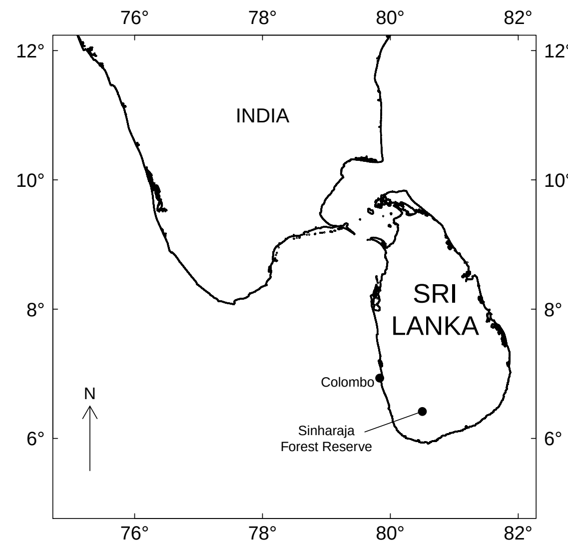


**Fig. 1.** Location of Sinharaja Forest Reserve within Sri Lanka.

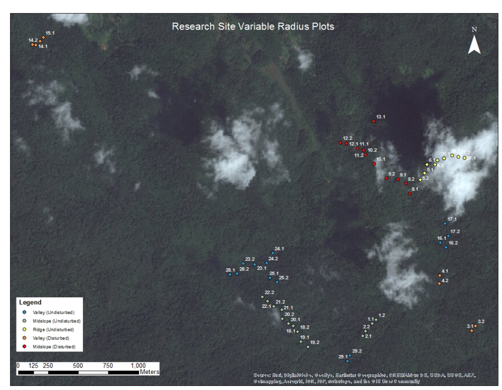


**Fig. 2.** Sampling locations within Sinharaja. *Note:* Projection is different to Google Earth; clouds did not hinder measurements.

Measuring forest stand structure responses to selective logging across a physiographic gradient and matching this to remotely sensed data could potentially advance our ability to interpret impacts through mapping. This study seeks to develop a localized methodology that could be used as guidance for forest planning, restoration, and conservation strategies. More specifically, this study seeks to answer the following questions:

1. Does Google Earth® provide sufficient data alone to characterize changes in forest structure across physiographic gradients?
2. Can mixed dipterocarp forests be evaluated using aerial imagery alone to characterize the effects of selective logging?

The study has widespread potential relevance to a forest type that is the richest timber type, in terms of biodiversity, within Southeast Asia and the most severely impacted from logging.

## Methods

*Study Site*

The chosen field site for the study is located at the northwestern boundary of the Sinharaja Forest Reserve, adjacent to the small village of Pitakele, Sri Lanka (6°24'56.8", 80°25'28.3", Fig. 1). This area contains an important array of land uses including managed mixed dipterocarp forest, home gardens, tea plantations, spice cultivation, rice paddy, second-growth forest, and some of the last contiguous protected primary forest. The location is exceptional in the sense that logged forest is adjacent to unlogged forest, providing an ideal site for comparison. Logging operations were conducted in 1975 and in 1990 in two separate managed areas, both adjacent to undisturbed forest. The topography of the research site is undulating ridge-valley (600-1000 m), the monsoonal rains average 5000 mm yr$^{-1}$, and the mean annual temperature is 27°C (Ashton et al., 1997; Blackenburg et al., 2004). The soils are deep well-drained (valley) to thin-skeletal (ridge) podsols or ultisols of khondalitic gneiss origin, (Moorman & Panabokke, 1961; Cooray, 1967; USDA, Soil Conservation Service 1975; Ashton et al., 1997; Ediriweera et al., 2008).

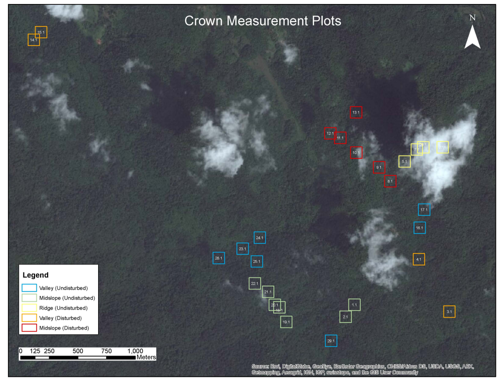


**Fig. 3.** Sampling locations of crown spread measurements across the research site. The center of the square plots is precisely the same as the center of the variable radius plots measured in the field.

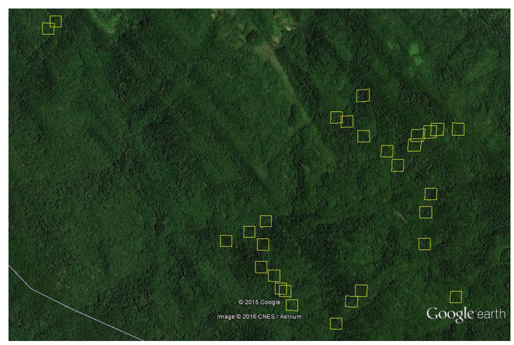


**Fig. 4.** Example of the actual imagery used to measure crown spread on Google Earth®. *Note:* Measurements were taken at a much finer resolution.

*Sampling Design*

During June and July of 2015, a forest inventory was carried out to provide ground-truthed data for comparison with data derived from Google Earth® imagery. Twenty-nine randomly selected sites (Fig. 2) were chosen along transects of different topographic positions to capture natural variation resulting from distinctive physiographic inputs. Within each site two variable radius plots

(VRP) were sampled. Sites were classified by disturbance history and elevation to capture variation resulting from inorganic disturbance, resulting in five possible categories: disturbed valley, disturbed midslope, undisturbed valley, undisturbed midslope, and undisturbed ridge. Disturbed ridge sites are unaccounted for because it is assumed there is a lack of this forest type because of operational limitations, difficult terrain, and a lack of incentive to harvest in such areas.

At each plot, a Garmin GPSMAP 64s handheld GPS unit (Garmin International Inc., 1200 E. 151st St. Olathe, KS 66062-3426) was used to record the location of the plot center. Waypoint averaging was used to more precisely record the location for use with ArcGIS and Google Earth®. From the plot center, the researchers thumb "approximately a BAF 2.296 angle gauge" was used to obtain 'in' trees to obtain an estimate of basal area; since distance to each tree was recorded from plot center, limiting distances could be computed to ensure accuracy. The bearing to each tree within the VRP with a diameter at breast height (dbh) above 30cm was recorded using a Silva® Ranger® compass, and the distance from plot center was measured using a meter tape. The crown spread of "in" trees was measured in four cardinal directions (0, 90, 180, and 270), respective of plot center, with a meter tape and clinometer to find the canopy drip line of each specimen. Heights for individuals were calculated using the clinometer where possible. Using the collected field data, basal area, crown area, and stem density could be derived for trees ≥30cm dbh.

### *Data Analysis*

For each plot, canopy width for emergent trees was measured and averaged using a fixed area of 10,000 square meters (1 ha) with the recorded GPS plot center serving as the centroid (Fig. 3). Using this shapefile as a reference, these plots were projected in Google Earth® (Fig. 4). Within each square plot, nine subplots were divided evenly within the square and the most prevalent tree chosen as a sample totaling nine samples per plot. Each sample was measured twice at perpendicular angles capturing the longest crown spread and the longest crown cross-spread following similar procedures to the "axis method" suggested by the American Forests Tree Measuring Guidelines, (American Forests, 2016). These samples were replicated across elevation gradients as well as in forest areas that were logged (1978 and 1990) and unlogged. Finally, the measurements were averaged for comparison with ground-truthed data, and to compare measurements across topographic positions and disturbance histories.

## Results

A total of 517 trees ≥30cm were recorded across 58 variable radius plots. Of the 517 trees, 508 were retained for analysis. Snags (n = 76) were retained possible explanation and correlation for potential observed gaps in aerial imagery. The number of trees per plot ranged from 5 to 15 (mean = 9, sd = 2.4). Tree DBH ranged from 30 cm (minimum size included in the plots) to 223 cm (mean = 61.6, sd = 28.7). Tree height ranged from 2 m (a snag) to 70 m (mean = 23.8, sd = 8.6). The 76 snags had a crown spread of 0. Crown spread of non-snags ranged from 1 m to 21.9 m (mean = 11.6, sd = 3.3).

The aerial imagery analysis resulted in 29 1-hectare plots. A total of 252 trees were measured for analysis of crown spread. Crown spread ranged from 7.3 m to 39.0 m (mean = 20.5, sd = 5.2).

### *Field data*

*DBH.*—Within undisturbed forest, tree DBH differed significantly between physiographic positions (ANOVA, $F_{2,318} = 6.289$, $p = 0.0021$, Fig. 5 A). Trees in ridge habitat were significantly smaller than trees in valley or midslope (linear regression, $t = -2.852$, $p = 0.00463$), although habitat explained little variation in tree DBH ($R^2 = 0.038$). Within selectively harvested forest, there was no significant difference between midslope and valley habitat (ANOVA, $F_{1,179} = 0.108$, $p = 0.74$). Over all physio-

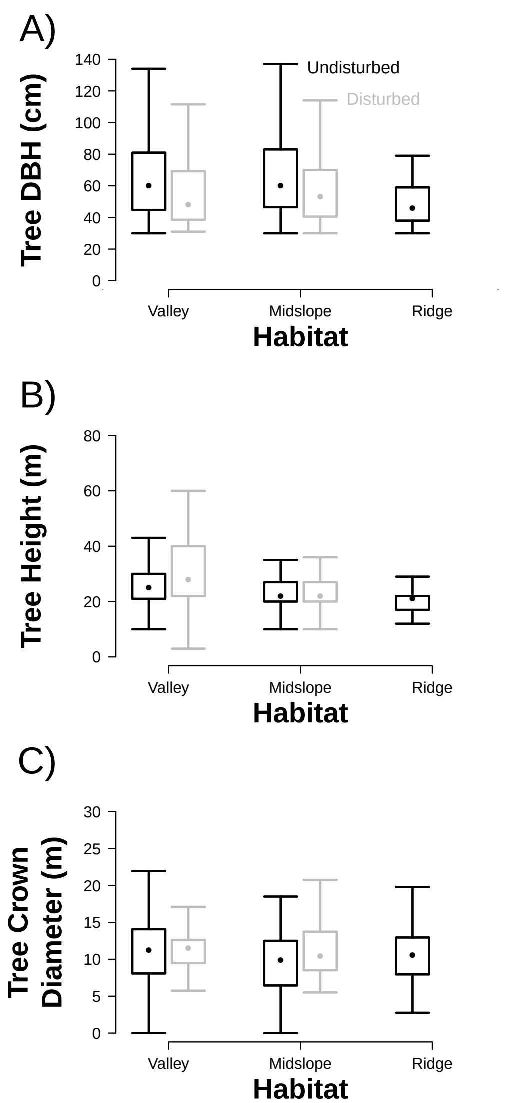


**Fig. 5.** Field measurements of tree structure from selectively harvested and undisturbed sites in Sinharaja Forest Reserve adjacent to Pitakele, taken from 29 sites. A) Tree diamater at breast height (DBH). B) Tree height, and C) Tree crown diameter. Black boxes indicate undisturbed sites, grey boxes indicate harvested/disturbed sites.

graphic positions, undisturbed forest trees had significantly greater DBH than selectively harvested forest, on average 10 cm greater (ANOVA, $F_{1,498}$ = 12.834, p < 0.001).

*Height.*—Within undisturbed forest, tree height differed significantly between physiographic positions (ANOVA, $F_{2,318}$= 14.1, p < 0.0001, Fig. 5 B). Trees in ridge habitat were significantly shorter than trees in midslope (linear regression, t = -2.862, p = 0.0045); trees in valley habitat were significantly taller than trees in midslope (linear regression, t = 2.948, p = 0.0034). Within selectively harvested forest, trees in valley were significantly taller than trees in midslope (ANOVA, $F_{1,179}$ = 33.1, p < 0.0001). Over all physiographic positions, trees in undisturbed forest were on average 1.8 m shorter than trees in selectively logged forest (ANOVA, $F_{1,498}$ = 5.061, p = 0.0249).

*Crown spread.*—Within undisturbed forest, tree height differed significantly between physiographic positions (ANOVA, $F_{2,260}$ = 3.44, p < 0.0154, Fig. 5 C). Trees in valley habitat (12.5 + 0.4) had significantly greater mean crown spread than trees in midslope (11.3 + 0.3) (linear regression, t = 2.438, p = 0.015). Within selectively harvested forest, there was no significant difference between midslope and valley habitat (ANOVA, $F_{1,161}$ = 0.062, p = 0.80). Over all physiographic positions, trees in undisturbed forest had on average 1 m smaller crown spread than trees in selectively logged forest (ANOVA, $F_{3,498}$ = 2.388, p = 0.0387).

### *GIS/Google Earth® Analysis*

Within the 29 plots located on Google Earth, 504 crown measurements were made (Fig. 6). Crown spread ranged from 7.3 m to 39.0 m (mean = 20.5, sd = 5.2). Within undisturbed sites, there was a significant difference in crown spread depending on position (ANOVA, $F_{1,159}$ = 8.877, p < 0.001). Valley sites had the greatest crown diameter (22.2 + 4.9 m), midslope was intermediate (21.6 + 6.80 m) and ridges contained the smallest mean crown diameter (17.5 + 3.7 m). Within selectively harvested sites, there were also significant differences in crown size (ANOVA, $F_{1,88}$ = 6.491, p = 0.013). Crown spread was greatest on midslope sites (20.5 + 0.5 m). Over all physiographic positions, trees in undisturbed forest had on average 2 m smaller crown diameter than trees in selectively logged forest (ANOVA, $F_{1,498} = 4.295$, $p = 0.0387$).

## Discussion

Data from the field and from remote sensing images found significant differences in tree structure and form between different physiographic habitats. Trees higher up on ridges or midslopes were shorter with smaller crowns than trees in valleys, in both undisturbed and selectively harvested forests. Trees in undisturbed forests, however, tended to be shorter, have smaller crowns, but larger trunks than trees in selectively logged forest.

Field sampling observations showed that both dbh, height, and crown spread were significant variables for characterizing forest at different topographic positions, especially in undisturbed forest. However, the differences were small (<2 m) for height and crown spread, limiting their usefulness for discerning forest history.

Comparisons of selectively harvested and undisturbed sites in terms of dbh and height showed that undisturbed sites had stronger trends than selectively harvested sites. Crown spread was sporadic in both site types. The low correlation among site and response variables is likely the result of selective harvesting. Undisturbed sites follow a more pure stratification based on resource gradients whereas selectively harvested sites are stratified according to resource gradients in addition to responses arising from disturbance regimes. These different stratification processes are discussed thoroughly by Ashton and Peters (1999).

Google Earth measurements showed high correlation of crown spread according to topographic position. These measurements followed similar trends as the response variables dbh and height for both disturbed and undisturbed sites. Selectively harvested sites and undisturbed sites could not be detected using this measurement alone.

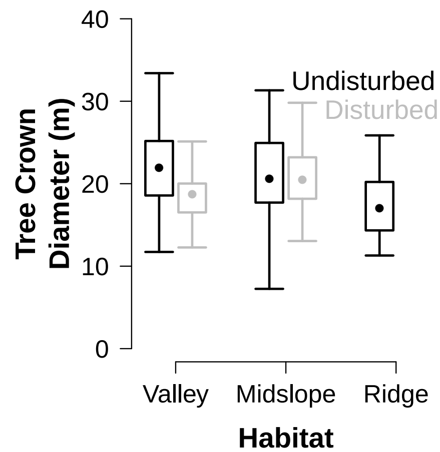


**Fig. 6.** Measurements of tree structure from selectively harvested and undisturbed sites in Sinharaja Forest Reserve adjacent to Pitakele, taken from Google Earth images.

Preliminary analysis of remotely sensed images using Landsat 8 found that imagery and data derived from remote sensing was difficult to obtain at the time of research and at a resolution too coarse for local characterization. Results of the analysis are in line with observations by Perera (2013) for MODIS imagery. No images were found (for the Sinharaja region) that were unobscured by atmospheric interference. Application of a tasseled-cap transformation, using coefficients by Baig et al., (2014), helped to distinguish different land classes. However pixel sizes of imagery were still too coarse to reveal the nature of tree crowns.

While accurate predictions of the complete stand structure cannot be achieved due to limitations in visibility from aerial imagery (smaller specimens are difficult to distinguish), much can be derived from the information for the assessed individuals above 30 cm dbh. Since these are often the canopy dominants, much of the basal area, density, and structure of the overall stand can be determined by these resource pools of which occupy the most biomass (Ploton et al., 2012). Much of the available resources are effectively locked up in these emergent trees, which may have implications for resource use in lower strata.

The trend of species stratification across physiographic gradients makes sense when taking into account resource gradients and individual's abilities to capture growing space following disturbance and based on their site restrictions (Ashton, 1995; Ashton et al, 1995; Gunatilleke et al, 1998; Gunatilleke et al., 2006; Poorter et al., 2006). Trees on undisturbed sites tend to decrease in size as one moves up slope. In this study, this phenomenon proved true for observed field parameters dbh and height but not average crown spread.

Interestingly, the trend of the measured crown spread as obtained from Google Earth® measurements followed the expected trends with respect to topographic position (undisturbed). However, the measured spreads were an order of magnitude greater than the field observations. This may be the result of field sampling error, or the fact that Google Earth® measurements were biased towards emergent trees. Field measuring protocol assigned measurements regardless of strata and were reliant on research technician's ability to be seen via angle gauge. The aerial reconnaissance derived from Google Earth® relied dominantly on the user's ability to discern the predominant canopy (emergent). This implies that some non-emergent 'in'trees within the variable radius plots were not detected by the satellite imagery. Additionally, the Google Earth® protocol encompassed a much greater area (1 ha) of which more emergent individuals could be included.

Since the trend of the Google Earth® measurements parallel field observations of dbh and height with respect to topographic position. Further study should investigate possible correlations among other response variables. Biomass and carbon could possibly be related to remote measurements from Google Earth® since they are often correlated to dbh and height. Depending on results, indices and further characterization could be developed which would greatly benefit forest planning and management, restoration, and conservation efforts.

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