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Assessing Atlantic cloud forest extent and protection status in southeastern Brazil

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ABSTRACT

This study aims to map the spatial distribution of Atlantic cloud forest and assess its protection status in the Serra da Mantiqueira, southeastern Brazil, using a combination of predictive distribution modelling and remote sensing techniques. The potential distribution of cloud forests in the Serra da Mantiqueira was predicted using a combination of three algorithms for different environmental variables, including climatic, hydrometeorological, a topographic variable and a fog-related variable. After estimating the potential cloud forest distribution, remote sensing mapping techniques were used to approximate actual cloud forest area. Four land-use classes were distinguished: cloud forest, plantation forest, a 'high-altitude complex', and 'other covers'. Actual mapped cloud forest areas were compared with locations of existing protected areas to assess the status of regional cloud forest protection. Predicted cloud forest distribution was excellent, with conditions above 1500 m.a.s.l. generally the most suitable for cloud forest occurrence. Actual cloud forest occurrence mapped with remote sensing imagery was 52% of the predicted potential area with differences likely due to past forest loss and the presence of non-forest ('high-altitude complex') vegetation. Much of the mapped cloud forest area is under nominal protection, with most areas falling into the 'Protected Area with Sustainable Use of Natural Resources' category. The combined use of predictive distribution modelling and remotely sensed observations successfully mapped cloud forest extent in the study area. The results reinforce the need to assign high conservation priority to the Serra da Mantiqueira as a whole and to create a core area with full protection status.

1. Introduction

Frequent fog (i.e., ground-based cloud occurrence) and persistently high atmospheric and soil humidity are key factors determining cloud forest occurrence (Bruijnzeel, Kapelle, Mulligan, & Scatena, 2010; Jarvis & Mulligan, 2011; Mulligan, 2010). Due to the narrow range of environmental conditions tolerated by many components of these fragile forests (notably bryophytes, vascular epiphytes, and amphibians; Ponce-Reyes et al., 2012; Pounds et al., 2006; Zotz & Bader, 2009), anthropogenic actions promoting climatic warming and drying, and therefore a rise in the lifting condensation level (i.e., the cloud base; Ray, Nair, Lawton, Welch, & Pielke Sr, 2006; Van der Molen, Dolman, Waterloo, & Bruijnzeel, 2006) form the main threat to the future of these forests along with habitat loss by conversion to other land uses (Mulligan, 2010; Ponce-Reyes, Nicholson, Baxter, Fuller, & Possingham, 2013). Although knowledge of the global occurrence and extent of

Abbreviations: SdM, Serra da Mantiqueira; CUFP, conservation units with full protection; SUPA, protected areas with sustainable use of natural resources; RF, random forest; SVM, support machine vector

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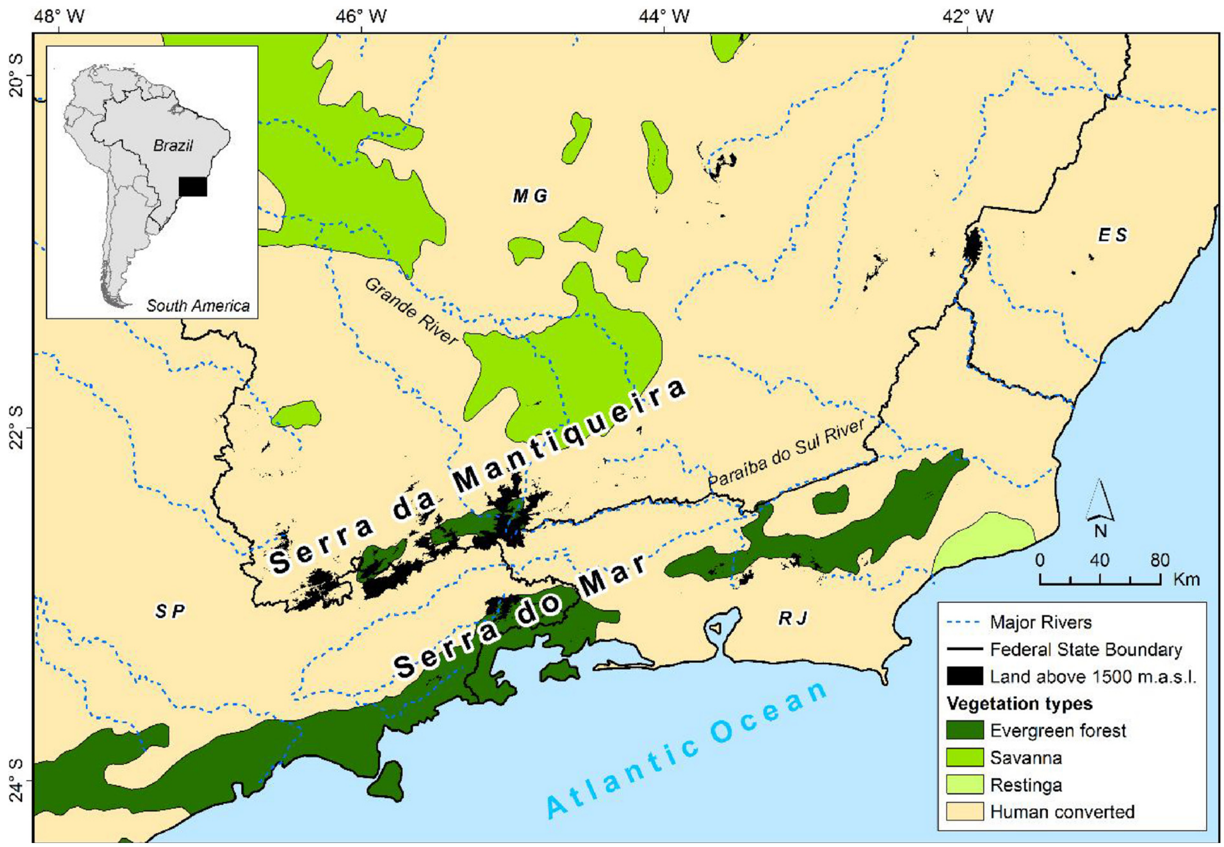


Fig. 1. Major physiographic, hydrographic and vegetation features of southeastern Brazil. In dark the land above 1500 m.a.s.l. where the predominant vegetation is cloud forest with the 'high-altitude complex' above the tree-line. Federal state: MG = Minas Gerais, ES = Espírito Santo, RJ = Rio de Janeiro & SP: São Paulo. Data source: IBGE, 2014.

tropical montane cloud forests has improved vastly over the last two decades (Mulligan, 2010), there is still much to be learned about their spatial distribution, biological richness and ecological variation at the local to regional scale. Therefore, fine-scale studies of montane cloud forest distribution (cf. discussion in Bruijnzeel et al., 2010) remain an important research priority.

The cloud-affected parts of the Mata Atlântica in Brazil represent a case in point. Not only is the Atlantic Forest one of the world's most important biodiversity hotspots (Myers, Mittermeier, Mittermeier, Fonseca, & Kent, 2000) but much of the remaining forest is highly fragmented and restricted to high-elevation areas in southern and southeastern Brazil (Bertoncello, Yamamoto, Meireles, & Sheperd, 2011). Estimates of the overall loss of Atlantic Forest *sensu lato* vary between 84% and 89% (i.e. 11–16% remains; Ribeiro, Metzger, Martensen, Ponzoni, & Hirota, 2009). The Mata Atlântica *s.l.* comprises a number of sub-types, including various rain forests and semi-deciduous forests as well as subtropical *Araucaria* forest whose floristics in southeastern Brazil has been described in some detail by Oliveira-Filho and Fontes (2000). Atlantic cloud forests have been much less researched botanically (Falkenberg & Voltolini, 1995; Pompeu et al., 2014) but a recent regional study indicated they constitute a distinct floristic and phytogeographical unit (Bertoncello et al., 2011). This opens up possibilities for mapping regional and local cloud forest extent based on the demonstrated occurrence of forest formation units (Webster, 1995). Some 60% of Brazil's original cloud-affected forest area is estimated to have been lost, with the country ranking second in terms of total area of cloud forest loss, after Mexico (Mulligan, 2010). The remaining cloud forests of southeastern Brazil occur primarily in two coastal mountain ranges (the Serra do Mar and the Aparados da Serra; Aldrich, Billington, Edwards, & Laidlaw, 1997) and in the Serra da Mantiqueira, a less explored mountain range located further inland. Knowledge of the floristic composition and biogeography of these montane forests is still limited (Bertoncello et al., 2011; Meireles & Shepherd, 2015; Pompeu et al., 2014).

The importance of the Serra da Mantiqueira (henceforth referred to as SdM) as a source of water was recognized well before European colonization, as evidenced by the mountains' name in the indigenous Tupí-Guarani language, which translates as 'Weeping Mountains' (Becker, Rodriguez, & Zamudio, 2013). The area has a pronounced dry season in winter, but severe drought effects appear to be compensated by the occurrence of frequent orographic fog (de Safford, 1999a). According to Mosaico Mantiqueira (2010) the SdM sustains numerous streams that provide water to rural towns and large urban centers in the Southeastern region and part of Rio de Janeiro State, besides being an important contributor to the Cantareira River System supplying the São Paulo metropolitan region. Despite this regional importance (Ribeiro et al., 2009), both the lack of a comprehensive forest management plan and steady encroachment by agriculture threaten the remaining Atlantic Forest in the SdM, and urgent action for its conservation is required (Becker et al., 2013). Le-Saout et al. (2013) similarly called for effective management and conservation of the SdM because of its unique vertebrate species assemblage.

Given the importance of fog and persistent high humidity to cloud forest occurrence (Jarvis & Mulligan, 2011), and the high spatial resolution required for mapping cloud forest in mountainous terrain, this study aims to estimate cloud forest extent and protection status in the SdM using a combination of predictive species distribution modelling and remotely sensed observations of vegetation occurrence.

2. Material and methods

2.1. Study area

The SdM is an inland mountain range extending over a length of ~400 km across the States of São Paulo, Espírito Santo, Minas Gerais and Rio de Janeiro in southeastern Brazil, with the greatest extent located in Minas Gerais (Fig. 1). The 'double escarpment' represented by the (more coastal) Serra do Mar and the (more inland) SdM forms the most prominent orographic feature of the Atlantic edge of the continent (Almeida & de Carneiro et al., 1998). According to IBGE (2014), the total area of the SdM is 60,225 km^2 and elevations range from 3 to 2798 m.a.s.l. However, there are no exact administrative or geographical boundaries established for the mountain range and estimates differ between authors (see discussion in Pelissari & Romaniuc Neto, 2013). For this reason, we constructed our own SdM delineation adapted from IBGE (2014) and Pelissari and Romaniuc Neto (2013).

At latitudes 21–23 S, the climate prevailing in most of the mountain range is humid temperate (Köppen-type Cwb) with a pronounced dry season in winter that intensifies with distance from the coast (de Safford, 1999a; Sá Júnior, Gonsaga, Silva, & Alves, 2012). The WorldClim database (Hijmans, Cameron, Parra, Jones, & Jarvis, 2005) for the study area suggests annual rainfall to range on average from about 1050 mm between (20–290 m.a.s.l.) to 2400 mm between (2090–2560 m.a.s.l.), with higher values found at higher elevations due to orographic effects (de Safford, 1999b). Depending on elevation, average annual temperature ranges from 25.0 °C between 40–277 m.a.s.l. to 9.5 °C between 2450–2670 m.a.s.l. (Hijmans et al., 2005). Frost occurs frequently at higher elevations during winter, but snow is rare (de Safford, 1999b).

Oliveira-Filho and Fontes (2000) distinguished various sub-types of tropical rain forest within the SdM based on elevation: Submontane Rain Forest (300–700 m.a.s.l.), Lower Montane Rain Forest (700–1100 m.a.s.l.), and Upper Montane Rain Forest (> 1100 m.a.s.l.) while on the drier northern and western slopes seasonal tropical Semi-deciduous Forest occurs. The start of Atlantic cloud forest occurrence in the SdM coincides with the general cloud condensation level around 1100 m.a.s.l. (Pompeu et al., 2014) but depending on topographic exposure this may be at elevations up to ~1500 m.a.s.l. (Veloso, Rangel Filho, & Lima, 1991). Depending on the geological substrate and soil characteristics (Benites, Schaefer, Mendonça, & Martin Neto, 2001) the tree-line occurs anywhere between 1400 and 2300 m.a.s.l. (de Safford, 1999a) above which the predominant vegetation is a 'high-altitude complex' (Benites, Schaeffer, Simas, & Santos, 2007). This tree-less vegetation complex includes both the so-called *campos de altitude* (typically found on igneous or metamorphic rocks and rich in endemic species; Benites et al., 2001; de Safford, 1999a cf. Ribeiro & Freitas, 2010) and the less widespread *campos rupestres* (rocky grassland on quartzites; de Vasconcelos et al., 2011). There are no coniferous forests in Brazil, but certain 'mixed forests' contain conifers (Backes, 2009), mostly *Araucaria angustifolia,* with *Podocarpus lambertii* as a common associate (Veblen et al., 2005) in scattered fragments within the SdM above 1500 m.a.s.l (Backes, 2009). According to Oliveira-Filho and Fontes (2000), the tree flora of the Semi-deciduous Forest is only a fraction of the much richer rain forest flora and consists mostly of a subset of species capable of coping with a longer dry season. Conversely, the Atlantic cloud forests were shown to be floristically distinct from the equally wet coastal Atlantic rain forests, with *Drimys brasiliensis, Ilex microdonta*, and *Weinmannia paulliniifolia* being key indicator species for the cloud forest (Bertoncello et al., 2011). In the SdM, cloud forests are also the preferred habitat of species like *Cabralea canjerana*, *Lamanonia ternata*, *Myrcia splendens*, *Myrsine umbellata*, as well as *Prunus myrtifolia* (Pompeu et al., 2014).

2.2. Predictive cloud forest distribution modelling

To model the distribution of cloud forest within the SdM three algorithms were used in R programming language: MAXENT (Maximum Entropy, implemented in the R package dismo (Hijmans, Phillips, Leathwick, & Elith, 2015), RF (Random Forest, implemented in the package randomForest (Liaw & Wiener, 2002), and SVM (Support Vector Machine, implemented in the R package kernlab (Karatzoglou, Smola, Hornik, & Zeileis, 2004), based on habitat occurrence records derived from extensive fieldwork. In doing so, cloud forest was treated as a species following the method of Carnaval and Moritz (2008) and Ponce-Reyes et al. (Ponce-Reyes et al., 2012; Ponce-Reyes et al., 2013).

Polygons were created across the SdM around areas with known (field confirmed) cloud forest to serve as validation points in the spatial modelling of cloud forest occurrence and random points were extracted from within the polygons using Hawth's Analysis tool in ArcGIS 10.3, thereby generating a total of 65 occurrence points for validation. Known locations of cloud forest areas were based on local literature (Carvalho, Fontes, & Oliveira-Filho, 2000; Costa et al., 2011; de Safford, 1999a; França & Stehmann, 2004; Meireles, Shepherd, & Kinoshita, 2008; Oliveira-Filho et al., 2004; Pompeu et al., 2014; Valente, Garcia, Salimena, & Oliveira-Filho, 2011) and personal knowledge of the first two authors. All 65 cloud forest point locations were confirmed as cloud forest based on vegetation traits during extensive field surveys. The main vegetation traits found in most of the cloud forest areas in SdM are like other tropical montane cloud forest areas, such as presence of bamboos, abundant moss cover and vascular epiphytes (bromeliads and orchids) on branches and stems (cf. Bruijnzeel, Mulligan, & Scatena, 2011). In addition, the presence of indicator species as mentioned before were observed (cf. Bertoncello et al., 2011; Pompeu et al., 2014).

Next, a set of environmental variables were tested as candidate predictors applying statistics analysis, such as linear correlation and a Principal Component Analysis (PCA) using software STATISTICA 12 (StatSoft, Inc., 2013). With this process, the collinear variables were removed, and the retained variables were chosen from its variability importance with the three first axis of the PCA. Thus, spatial distribution modelling was performed using a set of 10 non-correlated different environmental variables: climatic variables (six layers), hydrometeorological variables (three layers; including total fog inputs variable) and a topographic variable as listed in Table 1. The climatic layers were obtained from WorldClim global climate data version 2 (www.worldclim.org) at 30″ resolution or ~1 km (Fick & Hijmans, 2017). The hydrometeorological layers were obtained using the WaterWorld model (www.policysupport.org), also at 1 km resolution. WaterWorld is an online spatially distributed water budget modelling programme that allows assessments of water resources availability, water security, accounting for hydrological ecosystem services, climate change impacts, and impacts of land and water management (Mulligan, 2013). It does so, based on global datasets for climate, terrain and land cover and a detailed spatial model for water balance including fog inputs. Further, a digital elevation model (DEM) was created at 90 m resolution from Shuttle Radar Topography Mission (SRTM) data downloaded from de Miranda (2005) to create slope gradients using the Spatial Analyst tool in ArcGIS 10.3. However, elevation was not used as a separate variable in the modelling process because it co-varies with many of the climate variables tested here and presented less importance in terms of variability with the first axis of the PCA than the correlated selected variable (cf. Ponce-Reyes et al. (2012); Ponce-Reyes et al., 2013). This is not surprising, as WorldClim data are interpolated using elevation as a covariate and WaterWorld as a data source to calculate the output variables.

All selected variables were transformed to a common 1 km resolution by nearest-neighbor resampling. The respective layers (mapped variables) were projected according to the WGS 84 coordinate system. To select the variables that most explain the variability inside the multidimensional dataset, a Principal Component Analysis (PCA) was

Table 1
Percentage variability explanation of the environmental variables used in the predictive modelling according to PCA statistics (first two axes only, values in descending order for axis 1) and their respective units and source.

Variable	Percent variability explanation (axis 1)	Percent variability explanation (axis 2)	Variable source
Minimum temperature of coldest month (°C)	24.1	1.0	WorldClim
Precipitation of Wettest Month (mm)	19.3	0.9	WorldClim
Precipitation of Driest Month (mm)	19.2	9.1	WorldClim
Annual mean wind speed (m s^{-1})	14.7	4.3	WorldClim
Mean diurnal range (°C)	10.1	7.1	WorldClim
Annual total water balance (mm/yr)	7.3	15.5	WaterWorld
Total fog inputs (mm/yr)	4.9	5.9	WaterWorld
Annual mean solar radiation (kJm^{-2} day^{-1})	0.4	15	WorldClim
Annual total actual evapo-transpiration (mm/yr)	0	30.8	WaterWorld
Slope	0	10.4	Created from SRTM

carried out under the retained non-correlated variables used to perform the predictive model.

For each algorithm, predictions were applied through three cross-validation partition data (Franklin, 2009), randomly splitting the data into 67% of training data and 33% of testing data, while a maximum training sensitivity plus specificity threshold value (Liu, Newell, & White, 2016) was used to create a binary map of presences and absences according to the suitability values generated by the algorithms. Each algorithm model was evaluated as a quantitative measure of performance using True Skill Statistics (TSS, Allouche, Tsoar, & Kadmon, 2006), this evaluates the rate of right predictions of presence (sensibility) and absence (specificity) of the generated model. To do this evaluation we created 6500 pseudo-absence points (100 random points around each point of presence data within the SdM polygon to increase the general accuracy of the distribution modelling when presence data is limited (Lobo & Tognelli, 2011). After that, an ensemble map was generated using the sum of the successful algorithms.

2.3. Remotely sensed land-cover mapping

After estimating potential cloud forest distribution, remote sensing techniques were applied to map the actual cloud forest area and remove areas predicted to have cloud forest but no longer having trees present. For this, nine cloud-free Landsat OLI images (2016/2017) with processing level Level-2 Data Product were downloaded from the United States Geological Survey for Earth Observation and Science (USGS/EROS). The images cover the entire predicted map from SdM and have full terrain correction and reflectance processed at surface level. Scene information is presented on Table 2.

Four land-cover classes were defined for mapping: cloud forest (i.e. Forest in areas defined as potentially suitable for cloud forest), plantation forest, 'high-altitude complex' vegetation (*campos de altitude* plus *campos rupestres*) and 'other uses' (e.g. agriculture, water bodies, bare soil, urban areas). An object-oriented classification approach was adopted using ECOGNITION DEVELOPER 8.0 software (Trimble, 2010). In this approach, images need to be segmented before classification, for which a multi-resolution segmentation algorithm (Baatz & Schape, 2000) was used to extract spectral, textural and contextual information as attributes for land-cover classification. The criteria used to define the objects according to the respective spatial and spectral attributes were a scale parameter equal to 50 and shape/compactness criteria equal to 0.3/0.3 respectively, with equal weights for all bands of the image. The Fuzzy Logic algorithm was applied to classify the images based on a training sample of 30 image-objects per land cover class. From the training sample, the best parameters for classification were selected through a comparative histogram analysis among the classes. These parameters are calculated by band spectral information such as brightness, maximum difference, mean layer values, spectral band ratio, and the normalized difference vegetation index (NDVI). Image post-processing was performed to mitigate misclassifications resulting from automated classification, using a combination of expert knowledge and auxiliary data (e.g. high-spatial resolution images). Final map validation was carried out using 50 image-objects per class to calculate a confusion matrix and its accuracy measures, such as: the overall accuracy, the user's (inversely related to commission error) and producer's (inversely related to omission error) accuracies, and the Kappa index (Congalton & Green, 2009).

Table 2
Orbit, path and date of acquisition of the Landsat OLI imagery selected.

Orbit/Path	Date of acquisition
216/073	05/31/2016
216/074	05/31/2016
216/075	06/16/2016
217/074	08/10/2016
217/075	07/25/2016
218/075	09/05/2017
218/076	09/05/2017
219/075	08/11/2017
219/076	08/27/2017

Finally, the areas classified as having cloud forest were plotted on maps showing the boundaries of existing Protected Areas according to the Brazilian Ministry of the Environment website (MMA, 2014) to estimate the area of cloud Atlantic Forest within the SdM that is under some kind of formal protection. Two categories were considered, viz. Protected Areas with Sustainable Use of Natural Resources, and Conservation Units with Full Protection under Law No. 9985/2000 (Brazilian System of Conservation Sites-SNUC).

3. Results

3.1. Modelling cloud forest extent

The final prediction map was built based on the successful three algorithms (MAXENT, RF, SVM)

where all of the models showed a high TSS-value (> 0.90). Thus, indicating excellent prediction capacity (Allouche et al., 2006) with a greater probability of cloud forest occurrence located on the western part of SdM and corresponding with the higher parts of the mountain range (i.e. mostly above 1500 m.a.s.l. but occasionally down to 1100 m.a.s.l.; cf. Figs. 1 and 2). The total area potentially covered with cloud forest was estimated at 7788 km^2 or 12.9% of the total SdM area. The raster map representing the predicted suitability occurrence of cloud forest is given in Supplementary material (cloud_forest).

The variables that most explain variability used in the predictive modelling of cloud forest extent as evaluated by the PCA (where the first axis explained 37.3% of total variance) is shown in Table 1. The second PCA axis also proved important with 19.5% of total variance explained. In short, climatic variables were more important than hydro-meteorological variables to cloud forest presence. The most important

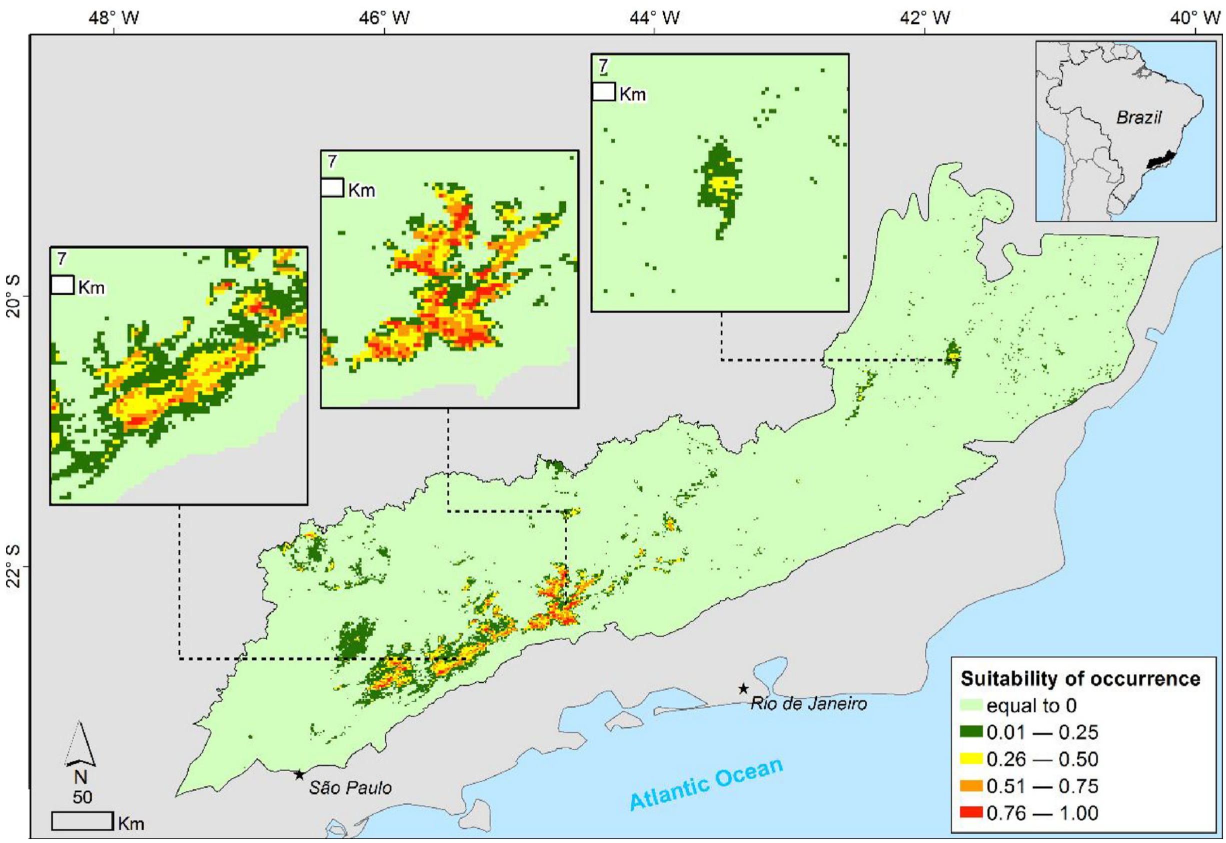


Fig. 2. Predicted spatial distribution of cloud forest in the Serra da Mantiqueira using the ensemble map from the algorithms applied (Maxent, Random Forest, and Support Vector Machine). The marks represent the two major towns of southeastern Brazil.

variables for the first axis were minimum temperature of coldest month and related to precipitation (precipitation of wettest month and precipitation of driest month), wind speed also proved important. For the second axis, the most important variables were associated with soil water availability (through annual total actual evapotranspiration and annual total water balance). The total fog inputs also demonstrated a considerable importance to the predicted model (Table 1).

3.2. Land-cover mapping

The object-oriented classification approach allowed the extraction of spectral and spatial features based on the main characteristics that distinguish the land cover classes such as: short-wave infrared channel (SWIR), NDVI and spatial attributes (Fig. 3).

Overall classification accuracy was 93% (user´s accuracy range: 85–98%, producer´s accuracy range: 88–98% amongst the respective cover classes) while the obtained Kappa index value was 0.91, thus showing excellent agreement (Fig. 4). The results of the confusion matrix are demonstrated in Fig. 4. The Cloud Forest class presented the lowest user's accuracy (85%), which means a commission error of 15%, and a producer's accuracy of 94%, meaning that most of the Cloud Forest areas (only 6% of omission error) were corrected mapped.

Based on the land-cover classification of the potential cloud forest area (7788 km^2), actual cloud forest extent (4074 km^2 or 52.3%) proved to be considerably smaller than predicted on the basis of climatic conditions alone because a significant area consisted of lands converted to other uses: agriculture and urbanization etc. made up 34.8% (2706 km^2) and high-altitude complex vegetation (9.4% or 728 km^2) while plantation forest occupied 3.6% (279 km^2) (Fig. 5). The land cover map is given in shapefile format in Supplementary material (land_cover).

3.3. Cloud forest protection status

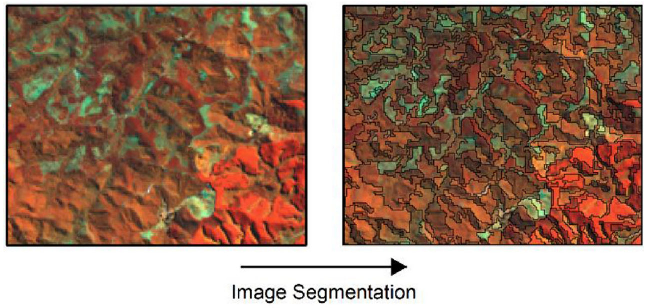
The currently modelled and mapped cloud forest areas within the SdM (4074 km^2) were compared with the boundaries of the two types of Protected Areas considered in the Brazilian conservation system, viz. Conservation Units with Full Protection (CUFP) and Protected Areas with Sustainable Use of Natural Resources (SUPA)[1] as shown in Fig. 6. Although a significant proportion of the mapped cloud forest area is under some form of protection (2815 km^2 or 69% of the total area), most of this (2104km^2 or 75% of protected land) is categorized as SUPAs while CUFPs represent 711 km^2 or 25% only.

Important well-known Protected Areas are shown in Fig. 6, and the complete list is given in Supplementary material (Table S1). Other areas indicated as having cloud vegetation include the highest ridges and peaks of the SdM being the third, fifth and sixth highest peaks in Brazil, respectively (i.e. the Pico da Bandeira (2891 m.a.s.l.), Pedra da Mina (2798 m.a.s.l.) and Pico das Agulhas Negras (2791 m.a.s.l) Fig. 6, where the dominant vegetation is comprised of the high-altitude complex with fragmented cloud forests beneath the tree-line.

4. Discussion

Various methods have been applied to estimate distribution and extent of tropical montane cloud forests previously. Using preset altitudinal limits as a proxy for the climatic and edaphic conditions typically associated with cloud forests, Bubb, May, Miles, and Sayer, 2004 estimated their potential area world-wide at 381,166 km^2 or 2.5%

[1] Note that the two protection categories show some aerial overlap. Because SUPAs themselves also overlap at times, the total area under SUPA considered here has taken any such overlaps into account. The SUPA polygon which shows another one overlapped had its common area eliminated.



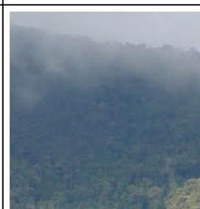
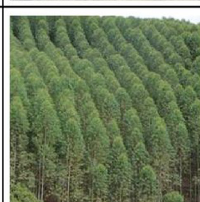
Land cover class	Image objects	Spectral/Spatial characteristics	Landscape picture
Cloud Forest	*Brown pixels*	- Low SWIR reflectance compared to HAC - NDVI values approximated 0.3 to 0.8 - Spatial heterogeneity	
High Altitude Complex (HAC)	*Green pixels*	- High SWIR reflectance compared to forest classes - NDVI around 0.3 - Spatial heterogeneity	
Planted Forest	*Red Pixels*	- Low SWIR reflectance compared to cloud forest - NDVI around 0.8 - Spatial homogeneity	
Others	Multiple colors	Heterogeneus	-

Fig. 3. Image segmentation process figure demonstrating the contours and colors of the different objects segmented plus the mainly spectral and spatial characteristics used for land-cover classification. In addition, landscape pictures representing the different classes. All pictures are in Serra da Mantiqueira. Image false-color composite: R = NIR, G = SWIR, B = Red; SWIR: short-wave infrared channel and NDVI: normalized difference vegetation index. See text for explanation (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article).

of the total tropical forest area in the year 2000. In a reiteration of the Bubb et al. (2004) analysis using MODIS satellite-based vegetation coverage for the year 2000 (VCF, 2000), Scatena, Bruijnzeel, Bubb, and Das, 2010 estimated the area of montane cloud forests between 30 °N and 30 °S at 214,630 km^2, representing 1.4% of the global tropical forest area and 6.6% of all tropical montane forests (> 300 m.a.s.l.). Conversely, a much higher estimate for ‘significantly cloud-affected forest’ area was obtained by Mulligan (2010) using a hydro-climatic approach in combination with MODIS_VCF 2000 vegetation data: 2,213,292 km^2 or 14.2% of all tropical forests. Mulligan (2010) considered his estimate to differ from the altitude-based cloud forest extent predicted by Scatena et al. (2010) because of the use of satellite imagery to derive areas with frequent or persistent fog (> 70% of the time) irrespective of elevation, and the use of remotely sensed continuous fields data to delineate all tree coverage > 10% instead of the 40% threshold used by Scatena et al. (2010). Also, the definition of hydro-climatically defined cloud-affected forests covers a much broader range

Reference Data

Classified Data	CF	HAC	PF	OT	Row Total
CF	47	3	1	4	55
HAC	0	46	0	2	48
PF	1	0	49	0	50
OT	2	1	0	44	47
Column Total	50	50	50	50	200

Overall Accuracy = 93% Kappa = 0.91

	CF	HAC	PF	OT
Producer´s Accuracy	94%	92%	98%	88%
User´s Accuracy	85%	96%	98%	94%

Fig. 4. Confusion matrix and accuracy results. Where: CF: Cloud Forest; HAC: High-altitude Complex; PF: Planted Forest and OT: Others.

of the cloud forest condition than cloud forests (ecologically defined). Cloud-affected forests were defined by Mulligan (2010) for their hydrological characteristics and it is no surprise that it may be much more extensive than cloud forests defined based on ecological or biological characteristics. The hydro-climatic approach yielded an estimated total area of 195,357 km^2 as being under cloud-affected forest (with forest defined as tree cover > 10% at 1 km resolution) for Brazil as a whole (Table 2.5 in Mulligan, 2010) which is greater than is possible for ecologically defined cloud-forests given the total area of remaining Mata Atlântica (all forest types) of 157,193 km^2 estimated by Ribeiro et al. (2009) and the limited extent of cloud forest in the Guyana Highlands according to Aldrich et al. (1997). Similarly, the hydro-climatic approach derived a total area of nearly 140,000 km^2 of cloud-affected forest in Mexico (> 10% tree cover; Table 2.5 in Mulligan, 2010) while Ponce-Reyes et al. (2013) using the same algorithm as the present study (i.e. representing a more ecological definition of cloud forest) obtained the much smaller value of 17,345 km^2.

These differences also partly reflect the high degree of fragmentation of many Atlantic forests which make global assessments at 1 km resolution challenging even using fractional covers as low as > 10%. Ribeiro et al. (2009) identified as many as 245,173 forest fragments in their survey of Atlantic forests, more than 80% of which were smaller than 50 ha while nearly 50% of forest extended less than 100 m from the nearest edge. Indeed, a much more restricted distribution was obtained for the cloud-affected forest in Brazil using the hydro-climatic approach when considering only ‘intact’ forest (canopy cover ≥ 70%) instead of the 10% threshold applied earlier (Mulligan, 2010), viz. ~30,000 km^2 vs. 53,500 km^2 for a tree-cover threshold of 50% (M. Mulligan, unpublished data). Further, the inclusion in the hydro-climatic approach of many small forest fragments may also lead to overestimation of the total ecologically defined cloud forest area because such areas might, in reality, be exposed to higher solar radiation (though also to higher fog impaction), which may affect key characteristics such as epiphytes and bryophytes. The advanced nature of forest disturbance and replacement in such areas is likely to have produced warmer and drier atmospheric conditions (Ray et al., 2006; Van der Molen et al., 2006) that are bound to affect such typical cloud forest attributes like epiphytes and bryophyte adversely (Nadkarni & Solano, 2002) although data from the SdM are lacking in this regard.

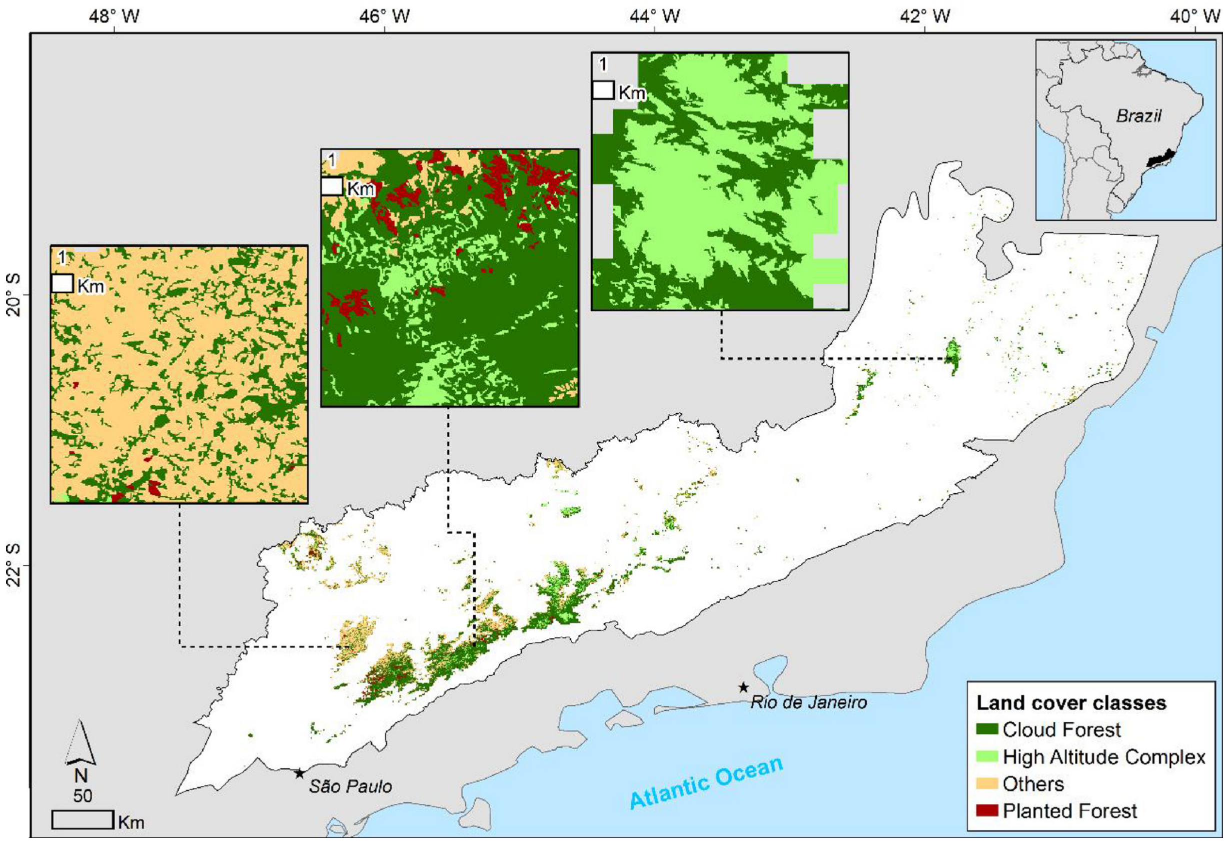


Fig. 5. Land-cover map for the Serra da Mantiqueira study area. Land-cover types distinguished within the modeled cloud forest area: High-Altitude Complex; Cloud Forest; Planted Forest; and Others. The marks represent the two major towns of southeastern Brazil. See text for explanation.

This study estimated the area of cloud forest in the SdM at 4074 km^2. Cloud forest occurrence was not strictly bound to elevation, presumably due to spatial differences in temperature and water availability; Table 1). Estimates of cloud forest area obtained with the hydro-climatic approach of Mulligan (2010) for the same shape mask using forest cover thresholds of 10%, 50%, and 70%, suggested values of 10,591, 3217 and 1224 km^2, respectively (M. Mulligan, unpublished data). The best agreement between results obtained with the current ecological modelling approach and the hydro-climatic approach is a 50% cover threshold. Areas with less than this cover are unlikely to be considered cloud forests ecologically even if they are hydro-climatically and thus hydrologically so.

Recent discussions are being made about the application of environmental variables in mountains areas showing the lack of precision of the first version of WorldClim database (Version 1.4; Hijmans et al., 2005) for such areas (van Gils et al., 2014), neglecting important topo-climatic process (Bobrowski, Gerlitz, & Schickhoff, 2017). In this study, the new database of WorldClim (version 2.0; Fick & Hijmans, 2017) was applied. This refined and expanded version include an increased number of climate stations, new stations located at high elevations and latitudes, and new variables such as solar radiation, wind speed and vapour pressure. Furthermore, WorldClim (version 2.0) improved its interpolation method adding new covariables such as distance of ocean and satellite-derived covariates (maximum and minimum land surface temperature and cloud cover) in addition to the elevation used in the previous version (Fick & Hijmans, 2017). Besides that, other data source was applied, the WaterWorld (Mulligan, 2013) adding important hydrometeorological variables for cloud forest such as fog inputs, water balance and actual evapo-transpiration based on monthly or diurnal cycle of distinct set of input variables characterising the climate, terrain and vegetation. In this study, the successful of the predicted map was assessed through the evaluation metric and the visual assessment of the distribution extent using authors knowledge expertise related with actual cloud forest distribution in SdM.

Of the hydro-climatic variables known to determine the location of different cloud forest formations (Jarvis & Mulligan, 2011; Scatena et al., 2010), some exerted a stronger influence than others in the SdM (Table 1) – notably temperature of coldest month, precipitation of wettest month, precipitation of driest month and wind speed– but combined, the modelling approach gave excellent predictions of cloud forest distribution within the SdM (Fig. 2). This good performance is likely due to the fact that these forests have well-defined climatic controls that typically differ from those associated with other forest types, i.e. cloud forests tend to be wetter and cooler (Jarvis & Mulligan, 2011). Here, our findings suggest the same, the cooler and wetter conditions are the main drivers for cloud forest occurrence. This wetter condition can be also inferred to the considerable importance of soil water availability (through annual total actual evapotranspiration and annual total water balance), and fog variable also contributing in this sense (Table 1). Furthermore, in cloud forests where there are higher wind speed values is expected to find higher inputs of occult precipitation meaning the sum of cloud-water interception and wind-driven rainfall (Bruijnzeel et al., 2011). Eller, Lima, and Oliveira, 2013 demonstrated the importance of foliar fog absorption during the dry season to the survival of Drimys brasiliensis, one of the key indicator species of cloud forest in the region (Eller et al., 2013; França & Stehmann, 2004; Meireles et al., 2008). In situ measurements of fog incidence and cloud water captured by the vegetation along elevational transects and its net effect on soil water status are desirable.

The high-altitude complex and (upper montane) cloud forest seem to depend upon the same hydro-climatic and physiographic features according to the algorithms. However, the tree-line (separating the two vegetation types) seems to be controlled by soil features, notably depth and texture, with the forest occurring on deeper and less sandy soils

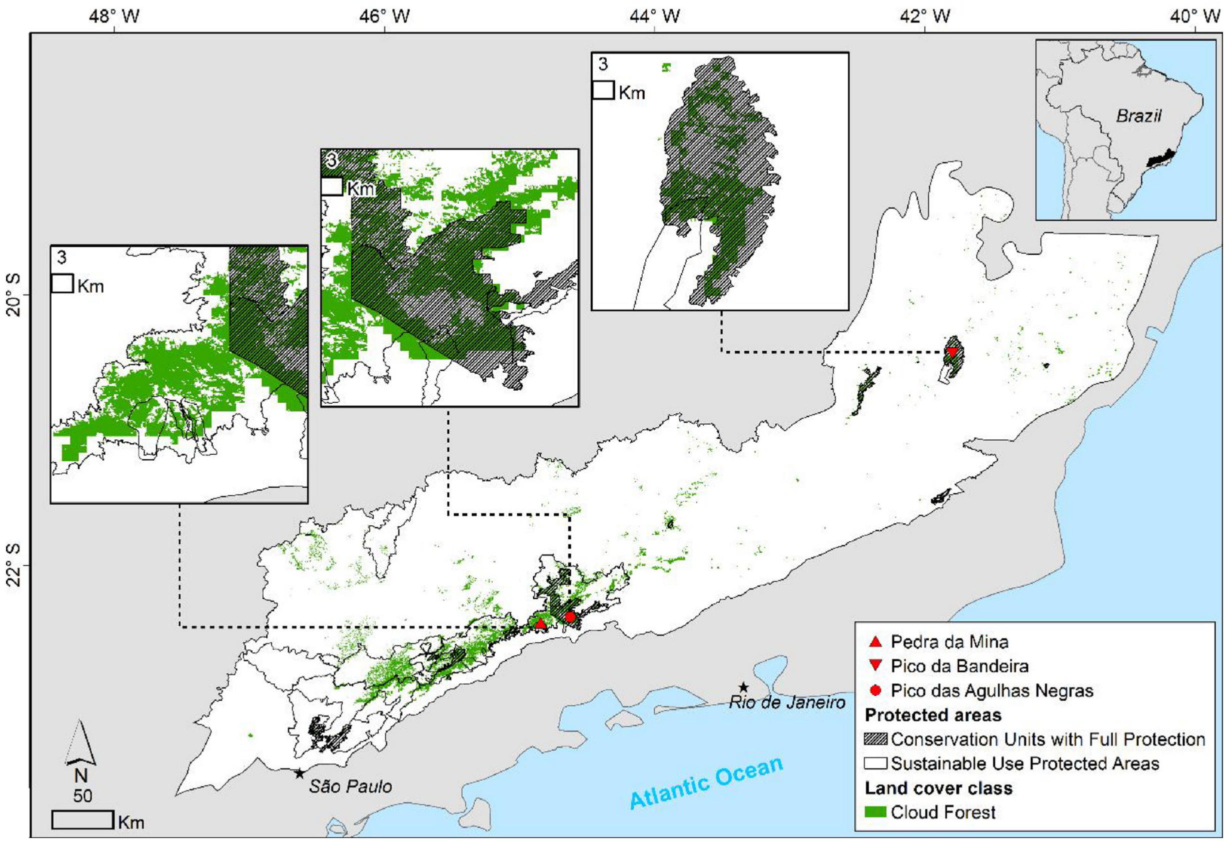


Fig. 6. Final mapped cloud forest areas compared with the location of Protected Areas, distinguishing between the two conservation categories within the Brazilian Conservation System. The red marks represent the highest peaks of Serra da Mantiqueira being among the higher in Brazil. The dark marks represent the two major towns of southeastern Brazil. See text for explanation (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article).

(Benites, Caiafa, Mendonça, Schaeffer, & Ker, 2003). Another possible tree-line control is fire regime, with forest occurring in locations where the fire is rarely or never occurring (de Safford et al., 2001). The present study estimated a surface area of 728 km^2 for the high-altitude complex, which is much higher than the $\sim$50 km^2 (located mostly on the Itatiaia plateau) mentioned by de Safford (1999a). These already ecologically and climatically vulnerable (de Safford, 1999b; Ribeiro & Freitas, 2010) ecosystems are threatened even more now because of a change in the Brazilian Forestry Code (see Ribeiro and Freitas (2010) for details). Other remarkable threat to these ecosystems in SdM is the rise of frequent anthropogenic fires, resulted mainly from agricultural practices (Aximoff & de Rodrigues, 2011; Bonfim, Ribeiro, Silva, & Braga, 2003; de Safford et al., 2001) which are often used in the dry period and many times ended up burning and transforming the cloud forests to other vegetation types (de Safford et al., 2001). In addition, regional warming may result in sharp increases in extinction rates because migration to higher altitudes is not possible (Ribeiro & Freitas, 2010). A similar effect may also apply to the cloud forests surrounding the high-altitude formations given the severely limiting soil conditions above the current tree-line (Benites et al., 2001). Another threat to the natural montane vegetation formations is coffee production which is projected to be displaced to higher elevations upon future warming (Assad, Pinto, Zullo, & Avila, 2004; Ribeiro & Freitas, 2010).

An important application of species distribution modelling relates to its use in choosing priority areas for protection (Franklin, 2013; cf. Ponce-Reyes et al., 2012). In this sense, the two maps supplied in the Supplementary Material: a land cover map (land_cover) and a suitability cloud forest occurrence map (cloud_forest) can be used for different purposes. For example, scientists can use these maps to choose their research areas and have an idea about the habitat extent of an endemic target species. Policy makers can use the maps to implement new protected areas, work with reforestation actions on human converted areas and payment of ecosystem services matters.

Although a representative part of the presently predicted cloud forest area within the SdM is at least nominally protected, the majority falls under the Sustainable Use (SUPA) category which has biodiversity conservation as a secondary objective and thus experiences some degree of human occupation (Rylands & Brandon, 2005). This is clearly insufficient to ensure the protection of the last cloud forests of the SdM which may represent only 2.6% of all remaining Atlantic forest (cf. Ribeiro et al., 2009) but have an extremely important hydrological role in addition to their very high biodiversity value (Becker et al., 2013; Le-Saout et al., 2013).

Only 17.5% of the mapped cloud forest area in the SdM currently falls into the strict protection category (CUFP). Thus, the creation of new protected areas in this category is urgently needed. In particular, the creation of a large and continuous block of fully protected cloud forest around the central part of the SDM that is currently not protected at all (around Pedra da Mina, Fig. 6) assumes special importance. The realization of an already proposed (Instituto Oikos de Agroecologia, 2009) Conservation Area of Full Protection (to be named Altos da Mantiqueira National Park) covering 87,000 ha and including this large and yet unprotected area would constitute an important biodiversity corridor (cf. Ribeiro et al., 2009; Becker et al., 2013). Unfortunately, Brazil still faces major obstacles to the implementation and management of its protected areas, with many examples of conservation areas existing largely on paper only (de Safford, 1999a; Falkenberg & Voltolini, 1995; Lima, Ribeiro, & Gonçalves, 2005). Perhaps the greatest challenge relates to competition for funding between government institutions in an environment of conflicting political interests

(Lima et al., 2005; Rylands & Brandon, 2005). Given the highly fragmented nature of the Atlantic Forest in general (Ribeiro et al., 2009), linking the remaining larger blocks of cloud forest in the SdM (and elsewhere) should receive priority.

5. Conclusion

The present study has demonstrated the usefulness of mapping montane cloud forest extent, although the spatial variability in biodiversity of different types of cloud forest in south-eastern Brazil is still comparatively poorly known at the finer scale (e.g., Carvalho et al., 2000; França & Stehmann, 2004; Oliveira-Filho et al., 2004; Pompeu et al., 2014). Further work is now necessary to identify the areas with the highest overall biodiversity (as well as the areas exhibiting the most favorable water balance in the SdM; cf. Mulligan & Burke, 2005). Brazil is currently recovering from a major water crisis (Escobar, 2015), and the SdM may constitute an important producer of water for the Southeastern region where much of the country's population is concentrated (Becker et al., 2013). The size of the area predicted to be under cloud forest within the SdM (4074 km^2) reinforces the conservation priority for important parts of the mountain range, where currently only 17.5% of the cloud forest falls into a strictly protected category within a biome that is already threatened (Ribeiro et al., 2009; *cf.* Myers et al., 2000). Additional studies of the biodiversity of different types of Brazilian cloud forests remain a necessity to further underpin the development of a sound public policy for the protection of these fragile forests and associated montane ecosystems such as the high-altitude complex (cf. Martinelli, 2007). Last, but not least, the overall rate of forest loss in the Atlantic Forest biome is still high, approaching 422 km^2 per year since 1985, and the last period 2015–2016 showed an increment of 58% related with the previous period studied 2014–2015 (Fundação SOS Mata Atlântica & INPE, 2017). At this rate of forest loss, without adequate protection cloud forests may also disappear within the next few decades, with grave consequences for the regional water supply (Becker et al., 2013; cf. Bruijnzeel et al., 2011). Adding the threat of the recent change in the country's Forestry Code, the high incidence of anthropogenic fires and the steady advance of coffee production to gradually increasing elevations (Assad et al., 2004; Aximoff & de Rodrigues, 2011; de Safford et al., 2001; Ribeiro & Freitas, 2010), it is not unthinkable that within a few decades the region's cloud forests will no longer exist through a combination of human disturbance and climate change.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at https://doi.org/10.1016/j.jnc.2018.04.003.

References

Aldrich, M., Billington, C., Edwards, M., & Laidlaw, R. (1997). *A global directory of Tropical Montane Cloud forests.* Cambridge: World Conservation Monitoring Centre, UNEP- WCMC.

Allouche, O., Tsoar, A., & Kadmon, R. (2006). Assessing the accuracy of species distribution models: Prevalence, kappa and the true skill statistic (TSS). *Journal of Applied Ecology, 43*, 1223–1232. http://dx.doi.org/10.1111/j.1365-2664.2006.01214.x.

Almeida, F. F. M., & de Carneiro, C. D. R. (1998). Origem e evolução da Serra do Mar. *Revista Brasileira De Geociências, 28*, 135–150.

Assad, E. D., Pinto, H. S., Zullo, J. R. J., & Avila, A. M. H. (2004). Impacto das mudanças climáticas no zoneamento agroclimático do café no Brasil. *Pesquisa Agropecuária Brasileira, 39*, 1057–1064. http://www.scielo.br/scielo.php?script=sci_serial&pid=0100-204X&lng=en&nrm=iso.

Aximoff, I., & de Rodrigues, R. C. (2011). Histórico dos incêndios florestais no Parque Nacional do Itatiaia. *Ciência Florestal, 21*, 83–92. http://www.scielo.br/scielo.php?script=sci_arttext&pid=S1980-50982011000100083&lng=en&nrm=iso.

Baatz, M., & Schape, A. (2000). Multiresolution segmentation: An optimization approach for high quality multiscale image segmentation. In J. Strobl, T. Blaschke, & G. Griesbner (Eds.). *Angewandte Geographische Informationsverarbeitung XII* (pp. 12–23). Heidelberg: Wichmann-Verlag.

Backes, A. (2009). Distribuição geográfica atual da Floresta com Araucária: Condicionamento climático. In C. R. Fonseca, A. F. Souza, A. M. Leal-Zanchet, T. L. Dutra, A. Backes, & G. Ganade (Eds.). *Floresta com Araucária: Ecologia, Conservação e Desenvolvimento Sustentável* (pp. 39–44). SP: Holos: Ribeirão Preto.

Becker, G., Rodriguez, D., & Zamudio, K. R. (2013). The Brazilian Adirondacks? *Science, 340*, 428. http://www.sciencemag.org/.

Benites, V. M., Caiafa, A. N., Mendonça, E. S., Schaeffer, C. E. G. R., & Ker, J. C. (2003). Solos e vegetação nos Complexos Rupestres de Altitude da Mantiqueira e do Espinhaço. *Revista Floresta e Ambiente, 10*, 76–85. http://www.floram.org/files/v10n1/v10n1a8.pdf.

Benites, V. M., Schaefer, C. E. G. R., Mendonça, E. S., & Martin Neto, L. (2001). Caracterização da matéria orgânica e micromorfologia de solos sob Campos de Altitude no Parque Estadual da Serra do Brigadeiro. *Revista Brasileira de Ciências de Solo, 25*, 661–674. http://www.scielo.br/scielo.php?script=sci_serial&pid=0100-0683&lng=en&nrm=iso.

Benites, V. M., Schaeffer, C. E. G. R., Simas, F. N. B., & Santos, H. G. (2007). Soils associated with rock outcrops in the Brazilian mountain ranges Mantiqueira and Espinhaço. *Revista Brasileira Botânica, 30*, 569–577. http://dx.doi.org/10.1590/S0100-84042007000400003.

Bertoncello, R., Yamamoto, K., Meireles, L. D., & Sheperd, G. J. (2011). A phytogeographic analysis of cloud forests and other forest subtypes amidst the Atlantic forests in south and southeast Brazil. *Biodiversity Conservation, 20*, 3413–3433. http://dx.doi.org/10.1007/s10531-011-0129-6.

Bonfim, V. R., Ribeiro, G. A., Silva, E., & Braga, G. M. (2003). Diagnóstico do uso do fogo no entorno do Parque Estadual da Serra do Brigadeiro (PESB), MG. *Revista Árvore, 27*, 87–94. http://www.scielo.br/scielo.php?script=sci_arttext&pid=S0100-67622003000100012&lng=en&nrm=iso.

Bobrowski, M., Gerlitz, L., & Schickhoff, U. (2017). Modelling the potential distribution of *Betula utilis* in the Himalaya. *Global Ecology and Conservation, 11*, 69–83. http://dx.doi.org/10.1016/j.gecco.2017.04.003.

Bruijnzeel, L. A., Kapelle, M., Mulligan, M., & Scatena, F. N. (2010). Tropical montane cloud forests: State of knowledge and sustainability perspectives in a changing world. In L. A. Bruijnzeel, F. N. Scatena, & L. S. Hamilton (Eds.). *Tropical Montane Cloud Forests. Science for conservation and management* (pp. 691–740). Cambridge: Cambridge University Press.

Bruijnzeel, L. A., Mulligan, M., & Scatena, F. N. (2011). Hydrometeorology of tropical montane cloud forests: Emerging patterns. *Hydrological Processes, 25*, 465–498. http://dx.doi.org/10.1002/hyp.7974.

Bubb, P., May, I. A., Miles, L., & Sayer, J. (2004). *Cloud Forest agenda.* Cambridge: UNEP WCMC. Accessed 30 June 2015 https://archive.org/details/cloudforestagend04bubb/.

Carnaval, A. C., & Moritz, C. (2008). Historical climate modelling predicts patterns of current biodiversity in the Brazilian Atlantic forest. *Journal of Biogeography, 35*, 1187–1201. http://dx.doi.org/10.1111/j.13652699.2007.01870.x.

Carvalho, L. M. T., Fontes, M. A. L., & Oliveira-Filho, A. T. (2000). Tree species distribution in canopy gaps and mature forest in an area of cloud forest of the Ibitipoca Range, southeastern Brazil. *Plant Ecology, 149*, 9–22. http://dx.doi.org/10.1023/A:1009836810707.

Congalton, R. G., & Green, K. (2009). *Assessing the accuracy of remotely sensed data: Principles and practices* (2nd ed). Boca Raton, FL: CRC Press, Taylor and Francis Group.

Costa, M. P., Pereira, J. A. A., Melo, P. H. A., Pífano, D. S., Pellicciottii, A. S., Pompeu, P. V., et al. (2011). Estrutura e diversidade da comunidade arbórea de uma floresta superomontana, no planalto de Poços de Caldas (MG). *Ciência Florestal, 21*, 711–725.

Eller, C. B., Lima, A. L., & Oliveira, R. S. (2013). Foliar uptake of fog water and transport belowground alleviates drought effects in the cloud forest tree species, *Drimys brasiliensis* (Winteraceae). *New Phytologist, 199*, 151–162. http://dx.doi.org/10.1111/nph.12248.

Escobar, H. (2015). Drought triggers alarms in Brazil's biggest metropolis. *Science, 347*, 812.

Falkenberg, D. B., & Voltolini, J. C. (1995). The montane cloud forest in Southern Brazil. In L. S. Hamilton, O. Juvik, & F. N. Scatena (Eds.). *Tropical Montane Cloud forests* (pp. 138–149). New York, NY: Springer-Verlag.

França, G. S., & Stehmann, J. R. (2004). Composição florística e estrutura do componente arbóreo de uma floresta altimontana no município de Camanducaia, Minas Gerais, Brasil. *Revista Brasileira de Botânica, 27*, 19–30. http://dx.doi.org/10.1590/S0100-84042004000100003.

Franklin, J. (2009). *Mapping species distributions: Spatial inference and prediction* (1st ed.). Cambridge: Cambridge University Press.

Franklin, J. (2013). Species distribution models in conservation biogeography: Developments and challenges. *Diversity and Distributions, 19*, 1217–1223. http://dx.doi.org/10.1111/ddi.12125.

Fick, S. E., & Hijmans, R. J. (2017). Worldclim 2: New 1-km spatial resolution climate

surfaces for global land areas. *International Journal of Climatology, 37*, 4302–4315. http://dx.doi.org/10.1002/joc.5086.
Fundação SOS Mata Atlântica, & INPE (2017). *Atlas dos remanescentes florestais da Mata Atlântica no período de 2015-2016.* Accessed 15 June 2017 https://www.sosma.org.br/link/Atlas_Mata_Atlantica_2015-2016_relatorio_tecnico_2017.pdf/.
van Gils, H., Westinga, E., Carafa, M., Antonucci, A., & Ciaschetti, G. (2014). Where the bears roam in Majella National Park, Italy. *Journal for Nature Conservation, 22*, 1617–1681. http://dx.doi.org/10.1016/j.jnc.2013.08.001.
Hijmans, R. J., Cameron, S. E., Parra, J. L., Jones, P. G., & Jarvis, A. (2005). Very high resolution interpolated climate surfaces for global land areas. *International Journal of Climatology, 25*, 1965–1978. http://dx.doi.org/10.1002/joc.1276.
Hijmans, R. J., Phillips, S., Leathwick, J., & Elith, J. (2015). *dismo: Species distribution modelling. R package version 1.0-12.* Vienna: The R Foundation for Statistical Computing. Accessed 5 May 2016 http://cran.r-project.org/.
IBGE (2014). *Instituto Brasileiro de Geografia e Estatística.* Accessed 10 July 2014 http://downloads.ibge.gov.br/downloads_geociencias.htm/.
Instituto Oikos de Agroecologia (2009). *Parque Nacional Altos da Mantiqueira.* Accessed 9 August 2015 http://pib.socioambiental.org/anexos/7308_20091208_100637.pdf/.
Jarvis, A., & Mulligan, M. (2011). The climate of tropical montane cloud forests. *Hydrological Processes, 25*, 327–343. http://dx.doi.org/10.1002/hyp.7847.
Karatzoglou, A., Smola, A., Hornik, K., & Zeileis, A. (2004). kernlab – An S4 package for Kernel methods in R. *Journal of Statistical Software, 11*, 1–20.
Le-Saout, S., Hoffmann, M., Shi, Y., Hughes, A., Bernard, C., Brooks, T. M., et al. (2013). Protected areas and effective biodiversity conservation. *Science, 342*, 803–805.
Liu, C., Newell, G., & White, M. (2016). On the selection of thresholds for predicting species occurrence with presence-only data. *Ecology and Evolution, 6*, 337–348. http://dx.doi.org/10.1002/ece3.1878.
Liaw, A., & Wiener, M. (2002). Classification and regression by random forest. *R News, 2*, 18–22.
Lima, G. S., Ribeiro, G. A., & Gonçalves, W. (2005). Avaliação da efetividade de manejo das unidades de conservação de proteção integral em Minas Gerais. *Revista Árvore, 29*, 647–653. http://dx.doi.org/10.1590/S0100-67622005000400017.
Lobo, J. M., & Tognelli, M. F. (2011). Exploring the effects of quantity and location of pseudo-absences and sampling biases on the performance of distribution models with limited point occurrence data. *Journal for Nature Conservation, 19*, 1–7. http://dx.doi.org/10.1016/j.jnc.2010.03.002.
Martinelli, G. (2007). Mountain biodiversity in Brazil. *Revista Brasileira Botânica, 30*, 587–597. http://dx.doi.org/10.1590/S0100-84042007000400005.
Meireles, L. D., Shepherd, G. J., & Kinoshita, L. S. (2008). Variações na composição florística e na estrutura fitossociológica de uma floresta ombrófila densa alto-montana na Serra da Mantiqueira, Monte Verde, MG. *Revista Brasileira de Botânica, 31*, 559–574. http://dx.doi.org/10.1590/S0100-84042008000400003.
Meireles, L. D., & Shepherd, G. J. (2015). Structure and floristic similarities of upper montane forests in Serra Fina mountain range, southeastern Brazil. *Acta Botanica Brasilica, 29*, 58–72. http://dx.doi.org/10.1590/0102-33062014abb3509.
de Miranda, E. E. (2005). *Brasil em relevo Embrapa Monitoramento por Satélite.* Accessed 24 June 2014 http://www.relevobr.cnpm.embrapa.br/.
MMA (2014). *Ministério do Meio Ambiente. Cadastro Nacional de Unidades de Conservação.* Accessed 12 June 2014 http://www.mma.gov.br/areas-protegidas/cadastro-nacional-de-ucs/dados-georreferenciados/.
Mantiqueira, Mosaico (2010). *Mosaico Mantiqueira.* March Accessed 12 June 2016 http://www.mosaicomantiqueira.org.br/site/o-mosaico/.
Mulligan, M., & Burke, S. M. (2005). *Global cloud forests and environmental change in a hydrological context.* http://www.ambiotek.com/cloudforests.
Mulligan, M. (2010). Modelling the tropics-wide extent and distribution of cloud forest and cloud forest loss, with implications for conservation priority. In L. A. Bruijnzeel, F. N. Scatena, & L. S. Hamilton (Eds.). *Tropical Montane Cloud forests. Science for conservation and management* (pp. 14–38). Cambridge: Cambridge University Press.
Mulligan, M. (2013). WaterWorld: A self-parameterising, physically based model for application in data-poor but problem-rich environments globally. *Hydrology Research, 44*, 748–769. http://dx.doi.org/10.2166/nh.2012.217.
Myers, N., Mittermeier, R. A., Mittermeier, C. G., Fonseca, G. A. B., & Kent, J. (2000). Biodiversity hotspots for conservation priorities. *Nature, 403*, 853–858. http://dx.doi.org/10.1038/35002501.
Nadkarni, N. M., & Solano, R. (2002). Potential effects of climate change on canopy communities in a tropical cloud forest: An experimental approach. *Oecologia, 131*, 580–586. http://dx.doi.org/10.1007/s00442-002-0899-3.
Oliveira-Filho, A. T., & Fontes, M. A. L. (2000). Patterns of floristic differentiation among Atlantic Forests in Southeastern Brazil and the influence of climate. *Biotropica, 32*, 793–810. http://dx.doi.org/10.1111/j.1744-7429.2000.tb00619.x.
Oliveira-Filho, A. T., Carvalho, D. A., Fontes, M. A. L., Van Den Berg, E., Curi, N., & Carvalho, W. A. C. (2004). Variações estruturais do compartimento arbóreo de uma floresta semidecídua alto-montana na chapada das Perdizes, Carrancas, MG. *Revista Brasileira Botânica, 27*, 291–309. http://dx.doi.org/10.1590/S0100-84042004000200009.
Pelissari, G., & Romaniuc Neto, S. (2013). *Ficus* (Moraceae) da Serra da Mantiqueira, Brasil. *Rodriguésia, 64*, 91–111. http://dx.doi.org/10.1590/S2175-78602013000100009.
Pompeu, P. V., Fontes, M. A. L., dos Santos, R. M., Garcia, P. O., Batista, T. A., Carvalho, W. A. C., & de Oliveira Filho, A. T. (2014). Floristic composition and structure of an upper montane cloud forest in the Serra da Mantiqueira Mountain Range of Brazil. *Acta Botanica Brasilica, 28*, 456–464. http://dx.doi.org/10.1590/0102-33062014abb3239.
Ponce-Reyes, R., Nicholson, E., Baxter, P. W. J., Fuller, R. A., & Possingham, H. (2013). Extinction risk in cloud forest fragments under climate change and habitat loss. *Diversity and Distributions, 19*, 518–529. http://dx.doi.org/10.1111/ddi.12064.
Ponce-Reyes, R., Reynoso-Rosales, V.-H., Watson, J. E. M., Van der Wal, J., Fuller, R. A., Pressey, R. L., et al. (2012). Vulnerability of cloud forest reserves in Mexico to climate change. *Nature Climate Change, 2*, 448–452. http://dx.doi.org/10.1038/NCLIMATE1453.
Pounds, J. A., Bustamante, M. R., Coloma, L. A., Consuegra, J. A., Fogden, M. P. L., Foster, P. N., et al. (2006). Widespread amphibian extinctions from epidemic disease driven by global warming. *Nature, 439*, 161–167. http://dx.doi.org/10.1038/nature04246.
Ray, D. K., Nair, U. S., Lawton, R. O., Welch, R. M., & Pielke Sr, R. A. (2006). Impact of land use on Costa Rican tropical montane cloud forests: Sensitivity of orographic cloud formation to deforestation in the plains. *Journal of Geophysical Research, 111*, 1–16. http://dx.doi.org/10.1029/2005JD006096.
Ribeiro, K. T., & Freitas, L. (2010). Impactos potenciais das alterações no Código Florestal sobre a vegetação de campos rupestres e campos de altitude. *Biota Neotropica, 10*(4), 239–246.
Ribeiro, M. C., Metzger, J. P., Martensen, A. C., Ponzoni, F. J., & Hirota, M. M. (2009). The Brazilian Atlantic forest: How much is left, and how is the remaining forest distributed? Implications for conservation. *Biology and Conservation, 142*, 1141–1153. http://dx.doi.org/10.1016/j.biocon.2009.02.021.
Rylands, A. B., & Brandon, K. (2005). Unidades de conservação brasileiras. *Megadiversidade, 1*, 27–35.
Sá Júnior, A., Gonsaga, L. C., Silva, F. F., & Alves, M. C. (2012). Application of the Köppen classification for climatic zoning in the state of Minas Gerais, Brazil. *Theoretical and Applied Climatology, 108*, 1–7. http://dx.doi.org/10.1007/s00704-011-0507-8.
de Safford, H. F. (1999a). Brazilian Páramos I. An introduction to the physical environment and vegetation of the campos de altitude. *Journal of Biogeography, 26*, 693–712. http://dx.doi.org/10.1046/j.1365-2699.1999.00313.x.
de Safford, H. F. (1999b). Brazilian Páramos II. Macro- and mesoclimate of the *campos de altitude* and affinities with high mountain climates of the tropical Andes and Costa Rica. *Journal of Biogeography, 26*, 713–737. http://dx.doi.org/10.1046/j.1365-2699.1999.00312.x.
de Safford, H. F. (2001). Brazilian Páramos III. Patterns and rates of Postfire regeneration in the Campos de Altitu de. *Biotropica, 33*, 282–302. http://dx.doi.org/10.1111/j.1744-7429.2001.tb00179.x.
Scatena, F. N., Bruijnzeel, L. A., Bubb, P., & Das, S. (2010). Setting the stage. In L. A. Bruijnzeel, F. N. Scatena, & L. S. Hamilton (Eds.). *Tropical Montane Cloud forests. Science for conservation and management* (pp. 3–13). Cambridge: Cambridge University Press.
StatSoft, Inc (2013). *STATISTICA (data analysis software system), version 12.* Tulsa,OK: StatSoft, Inc.
Trimble (2010). *eCognition® Developer 8.64.0 reference book. Müchen: Definiens Imaging.*
Valente, A. S. M., Garcia, P. O., Salimena, F. R. G., & Oliveira-Filho, A. T. (2011). Composição, estrutura e similaridade florística da Floresta Atlântica, na Serra Negra, Rio Preto – MG. *Rodriguésia, 62*, 321–340. http://dx.doi.org/10.1590/2175-7860201162209.
Van der Molen, M. K., Dolman, A. J., Waterloo, M. J., & Bruijnzeel, L. A. (2006). Climate is affected more by maritime than by continental land use change: A multiple-scale analysis. *Global and Planetary Change, 54*, 128–149. http://dx.doi.org/10.1016/j.gloplacha.2006.05.005.
de Vasconcelos, M. F. (2011). O que são campos rupestres e campos de altitu de nos topos de montanha do Leste do Brasil? *Revista Brasileira Botânica, 34*, 241–246. http://dx.doi.org/10.1590/S0100-84042011000200012.
Veblen, T. T., Armesto, J. J., Burns, B. R., Kitzberger, T., Lara, A., León, B., Young, K. R., et al. (2005). The coniferous forests of South America. In F. A. Anderson (Ed.). *Ecosystems of the world: Coniferous forests* (pp. 293–317). Amsterdam: Elsevier.
Veloso, H. P., Rangel Filho, A. L. R., & Lima, J. C. A. (1991). *Classificação da vegetação brasileira, adaptada a um sistema universal.* Rio de Janeiro, RJ: IBGE.
Webster, G. L. (1995). The panorama of Neotropical Cloud forests. In S. P. Churchill, H. Balslev, E. Forero, & J. L. Luteyn (Eds.). *Biodiversity and conservation of neotropical montane forests* (pp. 53–77). New York, NY: The New York Botanical Garden.
Zotz, G., & Bader, M. (2009). Epiphytic plants in a changing world: Global change effects on vascular and non-vascular epiphytes. In U. Lüttge, W. Beyschlag, & J. Cushman (Vol. Eds.), *Progress in botany: vol. 70*, (pp. 147–170). Berlin, Heidelberg: Springer-Verlag.