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ORCHID DISTRIBUTION AND BIOCLIMATIC NICHES AS A STRATEGY TO CLIMATE CHANGE IN AREAS OF TROPICAL DRY FOREST IN COLOMBIA

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Abstract. Climate change projections in Colombia predict an average increase in temperature of 2.6°C and in precipitation of 20% by the end of the century. These changes would directly affect the tropical dry forest (TDF) and its biodiversity. Epiphytic orchids, more exposed to the atmosphere than the terrestrial biota, remain dependent on climatic variables, making them particularly susceptible to climate change. We studied the spatial and temporal changes of a focal group of 12 orchid species typical of the TDF in Colombia, and the future conservation areas to this ecosystem. The algorithm used by MaxEnt was employed for modelling. A total of 439 records: direct observations (276); herbaria collections (159) and bibliographical sources (4) collected since September 2009 to April 2015 were considered for use in training the model. The actual potential niche was compared to the SRES 8.5 climate change emissions scenario for two periods: 2020–2049 (2030) and 2040–2069 (2050). The results indicate an altitudinal displacement compared to the present, conditioned by variables such as temperature, accessibility and precipitation. Mid-mountain areas (1300–1700 m) increased their idoneity in future potential niche models (2030 and 2050) to the detriment of the lowlands (0–1000 m). Other variables analysed, such as distance thresholds of pollinators (Euglossini), availability of phorophytes, and distances to TDF cover and protected areas, all suggest an improving connectivity between the lowland and mid-mountain areas. Consequently, bioclimatic niches (BN) are proposed as a new landscape management unit. Throughout the country, 69 of these BN were located as an adaptation-conservation strategy against climate change in the TDF in Colombia.

Resumen. Las proyecciones del cambio climático en Colombia, indican en promedio un incremento en 2.6°C de temperatura y 20% de la precipitación para el fin del siglo. Estos cambios afectarán directamente al bosque seco tropical (Bs-T) y su biodiversidad. Las orquídeas epífitas, más expuestas a la atmósfera que la biota terrestre mantienen dependencia de variables ligadas al clima. Esta condición las hace particularmente susceptibles al cambio climático. Nosotros estudiamos los cambios espacio-temporales de un grupo focal de 12 especies de orquídeas típicas del Bs-T en Colombia y las futuras áreas de conservación de este ecosistema. El algoritmo usado por MaxEnt fue empleado para el modelamiento. Un total de 439 registros: observaciones directas (276); registros de herbario (159) y fuentes bibliográficas (4), colectadas desde septiembre de 2009 hasta abril 2015 fueron consideradas para entrenar el modelo. El nicho potencial actual fue comparado con el escenario de emisiones de cambio climático SRES 8.5 para dos periodos: 2020–2049 (2030) y 2040–2069 (2050). Los resultados indican un desplazamiento altitudinal respecto al presente, condicionado por variables como: temperatura, accesibilidad, y precipitación. Las áreas de montaña media (1300–1700 m) incrementarán su idoneidad en los modelos de nicho potencial futuro (2030 y 2050) en detrimento de las tierras bajas (0–1000 m). Otras variables analizadas como umbrales de distancia en polinizadores (Euglossini), disponibilidad de forófitos, distancias a coberturas de Bs-T y áreas protegidas, sugieren mejorar la conectividad entre tierras bajas y áreas de montaña media. En consecuencia, los *nichos bioclimáticos* (BN) son propuestos como nueva unidad

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de manejo del paisaje. En todo el país, 69 de ellos fueron localizados como estrategia de adaptación-conservación frente al cambio climático en áreas de Bs-T en Colombia.

Key words: bioclimatic niches, climate change, Euglossini, orchids

Palabras clave: Bosque seco tropical, cambio climático, Euglossini, nichos bioclimáticos, orquídeas

Introduction. It is a challenging problem to understand and predict how organisms and plant communities respond to climate change and what is that response. A first research line focus on Bioclimatic Envelope Models (BEMs) still lack an ecological sense. Some authors use BEM to project the rank / abundance of current distribution of the species(s) including climate change (Bellard *et al.* 2012, Pearson & Dawson 2003, Thomas *et al.* 2004, Thuiller *et al.* 2004, Thuiller *et al.* 2008) and a second research line focus on controlled experiments (Bilton *et al.* 2016, Lloret *et al.* 2009, Peñuelas *et al.* 2007) but the models do not yet have ecologically meaningful processes representing orchids life cycle, *e.g.* dispersal, pollinating insects, phorophytes, mycorrhizae. We had included some of these as *a posteriori* analysis.

In this paper we define a "bioclimatic niches" from the evaluation of biotic and abiotic variables complementary to the model *per se* and we provided an ecological, dynamic and pragmatic sense to face the climatic change from the modelling of 12 orchids species in five areas of Tropical Dry Forest (TDF) in Colombia. The bioclimatic niches are areas where government and environmental agencies must focus conservation efforts.

Climate change and land-cover changes by anthropogenic activities are usually the main responsible factors altering the structure and function of ecosystems today (IPCC 2013). The climate change is direct threat of extinction of 4% of the vegetal species whereas the use of the land for livestock and crop farming is of 31%, the selective logging is 21.3% and the housing and commercial/industrial areas on the 12.3% (RBG Kew 2016). These stressors have caused devastating effects on the ecosystem and wiped out important chorological evidence for the management, reintroduction and conservation of orchids.

The lack of spatiotemporal scientific evidence from specific areas in basins and municipalities, where organisms will move into ecosystems, delays national and local conservation strategies facing the threat of climate change. Displacements of up to 500 meters in the plant zone are predicted in Colombia, affecting 23% of the country (Gutiérrez-Rey 2002). In addition, the national deforestation rate is approximately 200,000 ha/year, including of TDF, of which only 3.7% remains of what existed 150 years ago. These changes will significantly affect the five main TDF areas of the country, as well as the biodiversity they contain. With the aim of designing conservation strategies to address environmental change, the objective of this study consisted of identifying potential changes in the geographic distribution of a focal group of 12 orchid species typical of the Columbian TDF (Fig. 1).

Tropical Dry Forest (TDF)

This biome of lowlands and deciduous trees has three months or more of drought annually, with ecological processes marked by their seasonality (Pennington *et al.* 2006). Our data show no more than 32 orchids species/km^2 in Colombian TDF. During the Pleistocene, the TDF would have covered the inter-Andean valleys from northern to southern Colombia, providing refuge for flora and fauna (Hernández-Camacho & Sánchez 1992, Van der Hammen *et al.* 1973). Palynological evidence of areas of TDF in the Patía Valley, Cauca River Valley and savannah areas in the Eastern Plains (not included in this study) reveals the existence of these Pleistocene refuges in the last ten thousand years (Berrío *et al.* 2002a, 2002b, González-Carranza *et al.* 2008, Marchant *et al.* 2006, Vélez *et al.* 2005).

At present, according to Etter *et al.* (2008), 8.9 million hectares in Colombia may potentially contain TDF areas that are restricted to the Caribbean region, the Santander region, south of the Magdalena Valley, the Cauca River Valley, and the Patía Valley. However, deforestation processes and the land use transformation for cattle ranching and agriculture have caused devastating effects on the ecosystem. Currently, the extent of the remnant TDF is 720,000 ha, and moreover it is poorly and insufficiently represented in the National System of Protected Areas (NSPA,

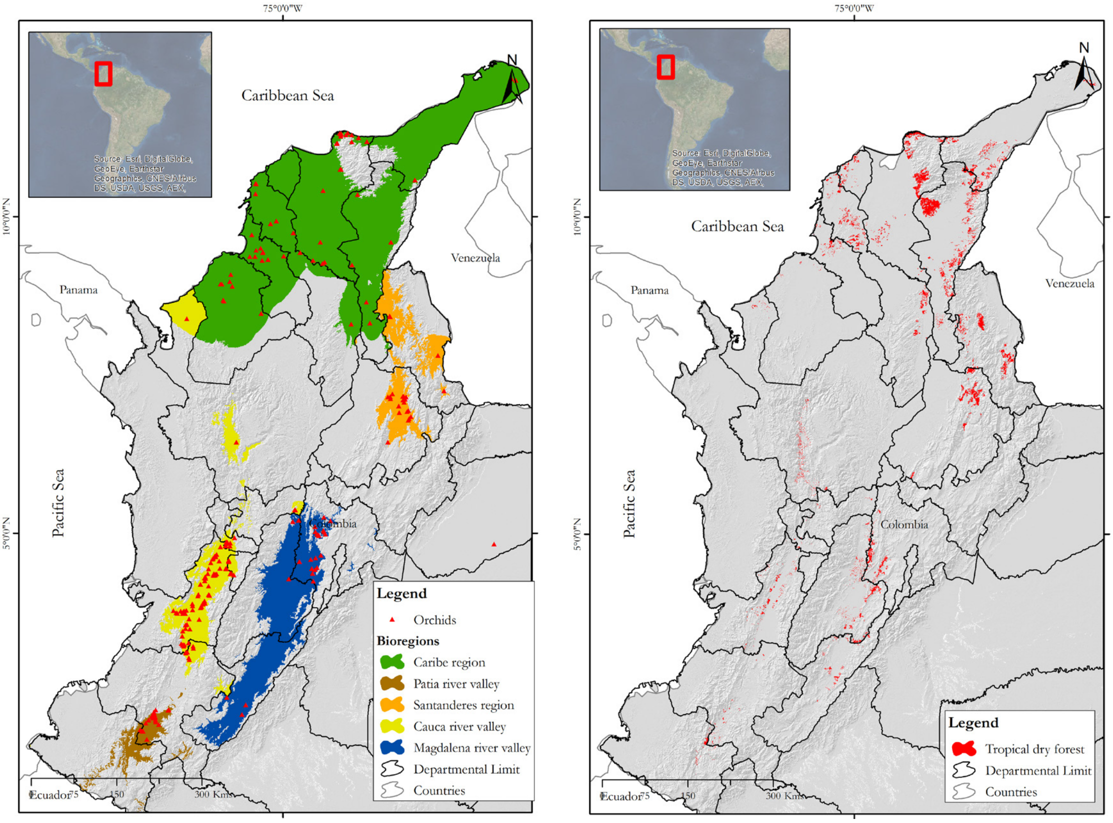

FIGURE 1. Left: Five main areas of potential TDF distribution in Colombia. Magdalena River Valley, Cauca River Valley, Caribbean region, Patía River Valley, Santander region. The red triangles indicate georeferenced records of TDF orchids in Colombia from field collections, herbarium sheets and bibliographic sources. Right: Actual distribution of TDF in Colombia. Source: Ariza *et al.* 2014.

in Spanish SINAP), because it accounts for only 5% (Pizano & García 2014).

By the 2071-2100, Colombian areas of TDF) are expected to have an increase in temperature of 2.4–2.8°C and will receive between 10 and 20% less rain (IDEAM *et al*. 2015). Climate change can also affect biota of the TDF through erratic or extreme rains, changes in evaporation, acceleration of erosive processes, modification of the microclimate and alteration of the composition of forest-grassland flora, as well as through an increase of the frequency of fires in the affected areas (Bates *et al.* 2008).

Orchids of the Tropical Dry Forest

Colombia with 4270 species of Orchidaceae reported, has the highest diversity of these plants in the world (Betancur *et al.* 2015). Their distribution, however, was defined by political-administrative areas, but not to bioregions of TDF associated with this taxonomic group, which remains a pending task. Plant inventories of the TDF reported only 81 species and 48 genera of orchids in Colombia (Pizano & García 2014), which is quite similar in number and composition to the 70 species and 41 genera reported for the TDF of the Cauca River Valley (Reina-Rodríguez *et al.* 2010). This fact can be attributed to scarce efforts and the difficulties of sampling of the epiphytic biotype (mostly between 10 and 40 meters above the ground). We estimated 350 orchid species present in these five areas of TDF in Colombia. However we believe that this number can increase because there are still many unexplored areas.

The marked seasonality of the TDF is manifested in the morphological and anatomical adaptations of these plants to conditions of prolonged drought (Oliveira & Sajo 2001) such as roots with velamen, idioblasts, trichomes and a thickened epidermis (Torres *et al*. 2007), all of which prevent water loss. Orchids and other epiphytes share light, temperature, moisture and nutrients in the forest canopy. The health of these plants is important to life cycles in the canopy, as well as to the ecosystem, not only for their contribution to trophic chains and microhabitats for invertebrates and amphibians but also because they serve as sinks of water (Richardson *et al.* 2000, Benzing 1998).

Orchids can respond to climate change challenges by shifting their climatic niche along three non-exclusive axes: time (e.g., phenology), space (e.g., range) and self (e.g., physiology) (Bellard *et al* 2012). The increase in temperature that will be induced by climate change will catalyse the migration of plants to higher latitudes and altitudes in search of suitable habitat (Chen *et al.* 2011). These natural migrations will maintain equilibrium with the climate and thus avoid potential extinctions (Feeley *et al.* 2010, Still *et al.* 1999). Such changes, however, modify the vegetation zone because migrations are closely linked to temperature increases (Primack & Corlett 2005). We identifying 69 high priority areas ("bioclimatic niches*"*) in Colombia where conservation efforts by land management agencies should be focused.

Materials and methods

Study area —. The TDF in Colombia includes localized areas between 12°24'33" and 1°39'35.31" latitude N and 77°21'31" and 70°27'43" longitude W, with an average annual temperature greater than 17°C. It corresponds to the lowlands and mountains with altitudes below 1500 m; the precipitation does not exceed 2000 mm, the rains are distinctly seasonal, and drought occurs for 3 months or longer (Mooney *et al.* 1995, Sánchez-Azofeifa *et al.* 2005). A population of 30.6 million people is settled in these areas (DANE 2015), which is equivalent to 63% of the Colombian population. The potential TDF cover in Colombia is 8.9 million ha, of which only 3.8% is conserved in its natural condition (Pizano & García 2014). Considering the possibility that climate change may alter the delimitation of the TDF, for this study, the territory was expanded to include areas with a total annual precipitation between 0 and 2100 mm and located at a maximum elevation of 1800 m (Fig. 1). TDF areas of the Eastern Plains (Casanare and Arauca) and insular Caribbean (San Andrés and Providencia) were not considered for this study due primarily to the presence of soils with laterite shields, which limit the potential vegetation (Pizano & García 2014) and secondly to the absence of primary information.

Collection of primary and secondary information —. During the 2009-2015 period, 1200 hours were spent gathering primary information, with 60 persons being directly or indirectly involved during 57 field trips. The areas explored included the TDF of the Cauca River Valley, the dry enclave of the Dagua River, the Patía River Valley, south of the Magdalena Valley, the Caribbean region and the department of Santander. More than 200 linear km were covered *ad libitum* with two or more expert observers, who used 8 x 40 binoculars to locate canopy orchids. The final expeditions were defined using the map of TDF in Colombia (Ariza *et al*. 2014) (Fig. 1).

In addition, geographic information was gathered from specialized scientific literature and botanical specimens deposited in the following 15 national and international herbaria: CUVC: Valley University, Cali; VALLE: National University, Palmira; TULV: Botanical Garden Juan María Céspedes Herbaria, Tuluá; CAUP: Cauca University, Popayán; CDMB: Eloy Valenzuela Botanical Garden, Floridablanca; COL: National Colombian Herbaria, Bogotá; FMB: Alexander von Humboldt Institute, Villa de Leyva; HUC: Córdoba University, Montería; Guillermo Piñeres Botanical Garden, Cartagena de Indias; UIS: Industrial University of Santander, Bucaramanga; UTMC: Magdalena University, Santa Marta; HPUJ: Pontifical Xavieriana University, Bogotá; Quindío University, Armenia; BC: Botanical Institute of Barcelona, Barcelona; and AMO: Mexican Association of Orchidology, México D.F. The data collected were sufficient for niche modeling and also improved the knowledge of the distribution range of these plants in areas of TDF in Colombia.

Orchid selection —. In total, 12 "*core*" species typical of TDF orchids in Colombia were selected; their classification and distribution ranges are shown in Appendix 1. Information from collections and/or field observations, as well as from the herbarium sheets, was compiled in a Darwin core format database (Wieczorek *et al.* 2012) available at http://rs.tdwg.org/dwc. This database consists of the 439 records were used to generate the model. The database also contains 314 aditional records of TDF orchid species different from the "*core*" species, as well as additional information, yielding a total of 753 records. Parts of these records are currently published as biological data sets in the form of three data sets; orchid associated flora-phorophytes, orchids observed in the field and orchids identified in herbaria which can be consulted in: http://i2d.humboldt.org.co/ceiba/resource.do?r=rrbb_bst_orquideas_2015; http://i2d.humboldt.org.co/ceiba/resource.do?r=rrbb_bst_orquideas_observaciones_2015 http://i2d.humboldt.org.co/ceiba/resource.do?r=rbb_bst_orquideas_identificaciones_2015

The selection criteria for these species were as follows: a) more than 18 records per species are required for greater reliability with MaxEnt; b) records were within the five areas of potential TDF delimited for Colombia; c) georeferenced records that occupy the same 1 × 1 km pixel were excluded to prevent over-estimation (over-fitting) in the model and to permit good discrimination between presences and pseudo-absences (Isaac *et al.* 2009, Van der Wal *et al.* 2009); d) species were geographically representative and complementary in TDF areas in Colombia such that they were present in most of the five areas studied. These characteristics are associated with the TDF species. Among the selected species, *Trizeuxis falcata* Lindl. has flattened and streamlined shapes to reduce the effects of the wind; *Cyrtopodium paniculatum* (Ruiz & Pav.) Garay and *Catasetum tabulare* Lindl. have large pseudobulbs and lose their leaves when the dry season is prolonged; *Epidendrum rigidum* Jacq., *Trichocentrum carthagenense* (Jacq.) M.W. Chase & N.H. Williams and *Polystachya foliosa* (Hook.) Rchb. have leathery leaves with thick cuticles to prevent water loss; *Vanilla calyculata* Schltr. has swollen stems to store a greater volume of water; and *Scaphyglottis prolifera* (Sw.) Cogn. has multiple elongated pseudobulbs as a strategy for water storage.

Modelling algorithm —. For modelling, the maximum entropy algorithm was used in the application MaxEnt (Elith *et al.* 2006, 2011, Phillips *et al.* 2006, Phillips & Dudík 2008). This algorithm uses maximum entropy and Bayesian methods to estimate the probability distribution of each species based on their presence or absence and pseudo-absences, which are defined as areas where presence or absence of the species is uncertain. The algorithm used by MaxEnt is one of the most robust models of species distribution (MSD) in terms of successfully estimating the area from only a few records of presence (Hernández *et al.* 2006), as occurs with most tropical epiphytes. MaxEnt has been widely tested for species idoneity in both present and future conditions (Merow *et al.* 2013, Phillips 2008, Reina-Rodríguez *et al.* 2016) and has been used with actual species from more than ten locations (Ramírez-Villegas *et al.* 2014, Wiz *et al.* 2008). In this study, to avoid *over-fitting* (Barbet-Massin *et al.* 2012), 2120 pseudo-absences were included, with ten for each presence obtained from our database (herbaria data and fieldwork) in TDF-delimited areas.

Given that a species can migrate and occupy new locations under future climatic conditions, we consider that by limiting the study area up to 1800 m and precipitation to 2100 mm/year, the thresholds of commission (too far from the niche of the taxon) and omission (lack of observations) are assumed implicit in the areas and periods proposed in this study.

Selection and preparation of modelling variables

For modelling, the potential niche or *habitat idoneity* is understood as the *n*-dimensional area where the species encounters the conditions that allow its survival and reproduction (Wiens *et al.* 2009). A total, 19 variables correspond to bioclimatic parameters associated with the baseline annual temperature and precipitation characteristics (1950-2000) (Hijmans *et al.* 2005) were selected. The other three variables were altitude, taken from the Digital Elevation Model (DEM) at 1 km (Jarvis *et al.* 2004); forest cover (Hansen *et al.* 2013); and accessibility, measured as time in minutes to get to a town of over 50,000 inhabitants, which was taken from the Joint Research Centre, available at http://ec.europa.eu/jrc/. Additional factors considered were the availability of free-access climatic data, a spatial resolution of 1 km and spatial cover. Large number of predictors in MaxEnt may cause excess in the

Table 1. Variables selected for the modelling of present and future scenarios. Bold indicates the seven variables selected by means of the Variance Inflation Factor (VIF) < 10. The (*) indicates variables excluded by low percentage contribution in the first iteration according to the model.

Variable	Brief Description	Unit of Measure	Source	VIF
Bio 2*	Average daytime temperature range	Degrees centigrade	Hijmans 2005	1.6
Bio 3	Isothermality. Index of temperature variability	Reason for average diurnal range with respect to annual range		3.5
Bio 4	Temperature seasonality	Standard deviation * 100		2.2
Bio 8	Average temperature of the wettest trimester	Degrees centigrade		2.2
Bio 13	Precipitation of the wettest month	Millimetres		2.3
Bio 14	Precipitation of the driest month	Millimetres		3.7
Bio 18*	Precipitation of the warmest trimester	Millimetres		1.5
Bio 19*	Precipitation of the coldest trimester	Millimetres		0.7
Tree cover	Forest cover	Percentage of area	Hansen 2013	2.1
Acc	Accessibility to population centres of more than 50,000 inhabitants	Time in minutes	Joint Research Centre	3.5

fit (*over-fitting)*, thereby skewing the responses (Warren & Seifert 2011). To reduce the number of variables, the Variance Inflation Factor statistical technique (VIF) was applied, which consists of a multiple regression analysis to identify the least co-linear variables among them, or, in other words, to determine which variables do not depend on others. The value VIF<10 (Montgomery *et al.* 2006) was used as a maximum threshold to reduce the number of variables for discarding in subsequent modelling routines (Austin & Van Niel 2011, Montgomery *et al.* 2006). This preliminary analysis reduced the number of variables to be used from 22 to 10. The Table 1 shows these variables used for performing the final routines for the climate of the present, near future (2030) and distant future (2050).

For modelling potential niches under climate change conditions, altitude and accessibility variables remained fixed. Forest cover was adjusted to an annual deforestation rate of 2% for 2030 and 4% for 2050, which was based on the current value reported in Colombia of 200,000 hectares per year (Reymondin *et al.* 2010). Climatic variables were taken from the projections conducted by the IPCC (2013), and the RCP 8.5 emission scenario of the fifth assessment report (AR5) was chosen for this study, specifically the projections for the 2020-2049 and 2040-2069 periods, referred to in this study as 2030 and 2050, respectively. This scenario was chosen because it represents the most likely path of events related to the production of greenhouse gases (GHG) emitted by the energy, industry, agriculture and forestry sectors, and it also combines interdisciplinary models that operate at different spatial resolutions and are interrelated and integrated into an overall evaluation framework (Riahi *et al.* 2007). The RCP 8.5 scenario predicts an increase of 2.7°C in average temperature and a change of 20% annual precipitation by the year 2069 and resembles the projections for Colombia conducted by IDEAM (2015) for the period 2041–2070.

Evaluation of model performance, behaviour and results

Three statistical methods were used to evaluate the quality and performance of the models obtained. Testing values for the area under the curve (AUC) indicate the ability of the model to discriminate presences from absences. AUC values oscillate between 0, which indicates randomness, to 1.0, which indicates greater discrimination (Engler *et al.* 2004); values of AUC<0.7 indicate poor models; values 0.7>*x*<0.9 indicate moderately useful models; and *x*>0.9 indicate excellent models (Pearce & Ferrier 2000). The Cohen's *Kappa* index was also calculated, which assesses the effect of randomness in associating observed objects to a specific classification category (Viera & Garret 2005). Concordance was thus identified from the results of the 25 iterations performed through *cross-validation* (Hijmans *et al.* 2012), using the sensitivity threshold *Maximum test sensitivity logistic threshold* as a reference (Liu *et al.* 2013). The model fit from the *Kappa* value was estimated by following the ranges proposed by Monserud & Leemans (1992) (See Appendix 2).

The spatial distribution patterns of orchids obtained for present and future conditions were quantified and compared to each other by identifying, for the entire study area, the potential gain or loss of the areas in which these species occur. To explore conservation strategies, this quantification also considered regional conglomerates of TDF, administrative units (Departments) and the Protected Areas listed in the Only National Register of Protected Areas (Registro Único Nacional de Áreas Protegidas – RUNAP) and in the Private Reserves of Civil Society (Reservas Privadas de la Sociedad Civil –NRCS), all of which have influence on the TDF areas throughout Colombia.

Idoneity indices —. Indices have been frequently used to estimate spatiotemporal changes (Armenteras *et al.* 2006, Mcgarigal & Marks 1995, Reina-Rodríguez & Soriano 2008, Rudas *et al.* 2002). In this study, three indices of idoneity were calculated for the 2030 and 2050 periods to assess the magnitude of future changes that can promote understanding of the spatiotemporal dynamics.

Index of tropical dry forest orchids IoBsT

This index represents the national magnitude of future idoneity, *IoBsT*_30 and *IoBsT*_50, compared to the present total idoneity.

$$IoBsT = \frac{Suitability_{t30,t50}}{Total\ Suitability_{tPresent}} * 100$$

Bioregional index of Tropical Dry Forest orchids IoBioreg

This index expresses the bioregional magnitude of future change, *IoBioreg*_30 and *IoBioreg*_50, with respect to the value of present idoneity in the bioregion in question.

$$IoBioreg = \frac{Suitability_{t30,t50}}{Suitability\ Bioregion_{tPresent}} * 10$$

Severity index of tropical dry forest orchids IoShp

The severity index expresses the strength or intensity of change. It is the ratio of the present idoneity with respect to the value of future idoneity, *IoShp*_30 and *IoShp*_50, in the bioregion in question.

$$IoShp = \frac{Suitability\ Bioregion_{tPresent}}{Suitability_{t30,t50}}$$

Proposal of bioclimatic niches —. Factors such as the persistence of certain species under climate change, migration speed, ecotones, immigration potential, and spatiotemporal plant-pollinator relations are excluded from predictive studies (Ibáñez 2006). Given that the current model generation does not consider factors that may increase biological realism and therefore approximation in future predictions (Urban 2015), *a posteriori* evaluations were proposed for the models obtained to identify where refuge areas for these plants would be in the Colombian TDF. A previous selection criteria filtered areas by river basins, with *p*>0.61 for the model obtained for the 2050 period. Subsequently, a Geographic Information System (GIS) and expert judgment were used to evaluate biotic and abiotic conditions complementary to the model. The biotic conditions were a) composition of the flora, b) presence of pollinators and c) presence of mycorrhizae. The abiotic conditions were a) altitudinal gradient, b) relief and c) distance to Protected Areas (PA and NRCS) and TDF fragments.

It was verified in 25% of the points, the presence of flora associated with at least three of the phorophytes reported in Table 2, were present within a radius of 23 km. From the biotic approach, wasps and bees are responsible for the transport and pollination of 60% of *Orchidaceae* (Ackerman 1983, Camargo *et al.* 2006, Whitten *et al.* 1993, Williams 1982). Large pollinators,

Table 2. Biotic and abiotic conditions evaluated for locating climatic niches proposed as a refuge for orchids of the Tropical Dry Forest (TDF) in Colombia.

Biotic conditios	**Requirements**
a) Composition of flora	Presence of at least three of these phorophytes: *Pseudobombax septenatum, Anacardium excelsum, Luehea seemannii* Planch. & Triana, *Guarea guidonia, Guazuma ulmifolia, Brosimum alicastrum, Calliandra pittieri, C. magdalenae, Samanea saman, Tetrorchidium rubrivenium* Poepp., *Guapira cf. costaricana* (Standl.) Woodson, *Ficus insipida, Erythroxylum ulei* O.E. Schulz, *Maclura tinctoria* (L.) D. Don ex Steud., *Crescentia cujete, Machaerium capote, Caesalpinia punctata* Willd., *Psidium guajava, Erythrina poeppigiana, Poulsenia armata* (Miq.) Standl., *Astronium graveolens* Jacq., *Sterculia apetala* (Jacq.) H.Karst and *Daphnopsis americana* (Mill.) J.R. Johnst.
b) Presence of pollinators	Presence of Euglossini bees (Hymenoptera: Apidae) such as *Eulaema*, *Euglossa, Eufriesea* and *Exaerete*. Thresholds less than 23 linear km are reached by these bees (Dressler 1982, Janzen 1971). Therefore, orchids and other TDF plants are also reached.
c) Mycorrhizae	Molecular studies of orchid-fungal associations, which indicate geographic range of mycorrhizal fungi are much larger than the range of the orchids themselves (Phillips *et al* 2014). Therefore we consider that forests of more than 10 ha and physiognomically well structured, harbor the mycorrhiza necessary for the development of seedlings.
Abiotic conditions	**Requirements**
a) Altitudinal gradient	Availability of 175 to 350 metres of altitudinal gradient in the next 25 to 50 years to compensate for an increase in temperature and possible extinctions (Feeley 2011, Lutz *et al.* 2013)
b) Relief	Moderate to very steep slopes. Presence of deep channels (canyons) with vegetated bottoms and slopes. Presence of rocky formations with cavities. Establishment of agriculture or population centres is not possible.
c) Distance to protected areas and/or fragments of TDF forest. Size of fragmented forest patches.	According to the TDF map (IAvH 2014) and the only national record of protected areas (RUNAP). Dense forest cover or sub-xerophytic shrubland greater than 10 ha (Harris 1984).

such as Euglossini bees (Hymenoptera: Apidae), have foraging routes up to 23 km long (Janzen 1971). Orchids pollinated by genera *Eulaema* Lepeletier, *Eufriesea* Cockerell, *Exaerete* Hoffmannsegg and *Euglossa* Latreille, can thermoregulate allowing them to fly under conditions of low humidity and high temperature, which are typical of open spaces (Janzen 1974, May & Casey 1983, Roubik 1993). They are present from Mexico to Argentina in several types of dry and semi-deciduous ecosystems (Rebêlo & Garófalo 1997), humid forests (Roubik & Ackerman 1987, Sandino 2004) and Amazonian forests (Becker *et al.* 1991). These pollinators ensure genetic variability through cross-pollination increasing the chance of surviving environmental changes and also migrate along altitudinal gradients from the lowlands to highlands in response to temperature increases and resource availability (Uehara-Prado & Garófalo 2006). This evolutionary adaptation gives this group of insects a key role under climate change conditions because in a short-term climate change effects are not expected for this group of organisms (Roberts 2003).

Emerging evidence from other molecular studies of orchid-fungal associations, indicate that geographic range of mycorrhizal fungi appears to be typically much larger than the range of the orchids themselves. (Phillips *et al.* 2014). For the analysis, we consider that forests of more than 10 ha and physiognomically well structured, harbour the orchid mycorrhiza necessary for the development of seedlings.

Results

Current knowledge of the orchids of TDF in Colombia —. Preliminary data of Orchidaceae in the TDF of Colombia indicate that 53 species exist in the Caribbean bioregion at altitudes <1000 m (Betancur *et al.* 2015); 127 species in the Santander bioregion (Martínez *et al.* 2015); 73 species in the Magdalena Valley (Bernal *et al.* 2015), with data mainly from the north (Antioquia) with gaps towards the south (Huila, Tolima); and 70 species in the Cauca River Valley (Reina-Rodríguez *et al.* 2010). According to our data on the Patía Valley,

Table 3. Representativeness of the selected species in the Colombian Tropical Dry Forest (TDF) . In *each cell,* the number of *records* of the species from the database generated for all Colombia is shown. Numbers in bold are higher than the average. PV= Patia river valley, CV= Cauca river valley, MV= Magdalena river valley, SR= Santander region, CR= Caribbean region.

	Regions of tropical dry forest (Bs-T) in Colombia					
Species	**PV**	**CV**	**MV**	**SR**	**CR**	**Total species records**
Brassavola nodosa (L.) Lindl	0	0	3	4	20	27
Catasetum tabulare Lindl	14	11	2	0	1	28
Cyrtopodium paniculatum (Ruiz & Pav.) Garay	7	13	2	5	28	**55**
Dimerandra emarginata (G. Mey.) Hoehne	1	25	2	9	13	**50**
Epidendrum rigidum Jacq.	3	19	6	2	2	32
Jacquiniella globosa (Jacq.) Schltr	0	23	4	2	2	31
Oeceoclades maculata (Lindl.) Lindl	7	6	5	11	19	**48**
Polystachya foliosa (Hook.) Rchb.f.	0	14	6	2	4	26
Scaphyglottis prolifera (Sw.) Cogn.	0	21	5	6	2	34
Trichocentrum carthagenense (Jacq.) M.W. Chase & N.H. Williams	1	19	3	5	12	**40**
Trizeuxis falcata Lindl.	7	22	8	12	1	**50**
Vanilla calyculata Schltr.	4	12	1	0	1	18
Total regional records	45	**185**	48	56	**105**	439

orchids species would not exceed 30 species. This group would be the most vulnerable to the effects of Climate Change due to the total absence of conservation areas.

The database compiled in the Darwin core contains 439 records of orchids from the Colombian TDF, of which, 276 correspond to herbarium collections, 159 to direct observations and four to bibliographic sources. Data indicate the presence of these taxa in five TDF areas in Colombian territory. The TDF map for Colombia, which was elaborated by the Alexander von Humboldt Institute (Ariza *et al.* 2014) and discussed by Pizano & García (2014), places the TDF ecosystem in Colombia in 22 departments and 314 municipalities. Concerning our 12 focal orchids support the presence of these plants in 19 departments and 118 municipalities. In other words, slightly more than half of the municipalities (196) lack records for these species, suggesting important geographical information gaps. By bioregion, the Cauca River Valley and the Caribbean region have higher than average values. The Patía River Valley and Magdalena River Valley have the poorest values. The representativeness of each 'core' species of the TDF is shown in Table 3.

Evaluation of the model and influencing variables —. From the filtering of the 439 records of our database, 212 points (one record per pixel of 1 km^2) were selected for these training tests. The AUC values for training tests of the twelve species ranged between 0.8562 and 0.8641, with x'=0.8598, whereas the test data ranged between 0.6702 and 0.9721, with 0.8126. AUC data for future periods yielded a value of 0.8825, and those from the test yielded 0.7570. Because the values have an AUC>0.7, the model is considered *'very good'* (Pearce & Ferrier 2000) and is consistent for species discrimination. The Kappa index demonstrates model performance and compares model prediction to random prediction (Naoki *et al.* 2006). In other words, it is a measure to assess the random effect and its concordance with what is observed. For our analysis, the degree of agreement is 0.85, which is within the 0.85 $\leq K<0.99$ range and qualifies it as *excellent* according to (Monserud & Leemans 1992), which indicates a high degree of agreement; therefore, the data used in the modelling can be regarded as reliable.

The most important variables in the model were the seasonality of temperature **Bio 4**, which explained

Table 4: *Bioclimatic niches* for the 2050 period and proximity to tropical dry forest (TDF) areas (Ariza *et al.* 2014), public protectec areas (PA) and private protected areas (NRCS) in the five bioregions of TDF in Colombia.

Bioregion	(a) Number of basins with suitability areas *p* > 0.61	Suitability areas *p* > 0.61 (ha)	(b) No. Polygons of TDF < 23 km (ha)	Areas of TDF < 23 km (ha)	(c) No. PA < 23 km	Area of PA < 23 km (ha)	(d) No. NRCS < 23 km	Areas of NRCS < 23 km (ha)	Altitudinal range: (a-b); (a-c); (a-d) (meters)
Cauca River Valley	13	115,256	239	28,111	25	62,571	23	946	629-1796
Caribbean Region	8	4756	91	76,436	0	-	2	446	0-1485
Magdalena Valley	15	49,061	157	63,848	16	33,320	4	13	237-1790
Patía Valley	1	9299	10	1.186	0	-	0	-	612-1443
Santander Region	8	9235	112	76,205	11	57,236	0	-	154-1798
Total	**45**	**187,607**	**609**	**245,786**	**52**	**153,127**	**30**	**1405**	**0-1798**

26.9%; the average temperature of the wettest trimester **Bio 8**, which explained 22.9%; and isothermality **Bio 3**, which explained 3.5%. These variables account for a total of 53% of the thermal influence and, consequently, the altitudinal influence in the model explanation. Accessibility to population centres of more than 50,000 inhabitants contributed 35.1%, which suggests a negative anthropogenic influence from proximity to urban and populated areas to locations where populations of orchids are found. Precipitation of the wettest month **Bio 13** explained 2.3%, and precipitation of the driest month **Bio 14** explained 3.7%, together add up to 6% of the explanation being influenced by the contribution of water seasonality to the model, is obviously indispensable for epiphytic and terrestrial orchids in terms of their physiological requirements, with the orchids depending on water reserves held in their specialized morphological structures. Finally, the forest cover explained 2.1%, which demonstrates the importance of a defined forested structure and, more specifically, the need for suitable phorophytes for the establishment of orchids.

Altitudinal migration of tropical dry forest orchids —. Data points obtained from the modelling totalled n=16,547, with idoneity $p>0.61$ and a pixel size of 1 km^2. The ANOVA results indicated statistically significant differences among the different combinations of the periods analysed (present–2030, present–2050 and 2030–2050) with $p<0.05$, showing drastic changes between the periods and also bioregion in the altitudes required by these plants, which are attributed to the effect of climatic change, reflecting the areas suitable for orchids in TDF for the next 50 years (see Appendix 3). The Caribbean region would be at approximately 954.3±141.1 SD m during the 2050 period, while the bioregion of the Cauca River Valley for the same period would be at 1393.6±183.4 SD m, identified as a suitable altitude under future climate scenarios according to the model. In the Caribbean bioregion, the availability of area will be concentrated at the Sierra Nevada of Santa Marta where net idoneity and forest cover still exists in 6 basin (see Appendix 5). At the other extreme, the suitability for orchids in the Cauca River Valley there is availability of areas and altitude gradients found below 15 km distance of the current populations in both the Dagua Canyon and Cauca River Valley; however, anthropogenic factors limit the coverage required for the establishment of these plants (Reina-Rodríguez *et al.* 2016).

On the other hand, the Patía and Santander bioregions show similarities in the 2030 period (1121.3±174.3 SD m and 1140.9±166.7 SD m, respectively) and the 2050 period (1269.7±147.1 SD and 1275.5±150.6 SD, respectively) in the altitudinal suitability requirements for both periods and also

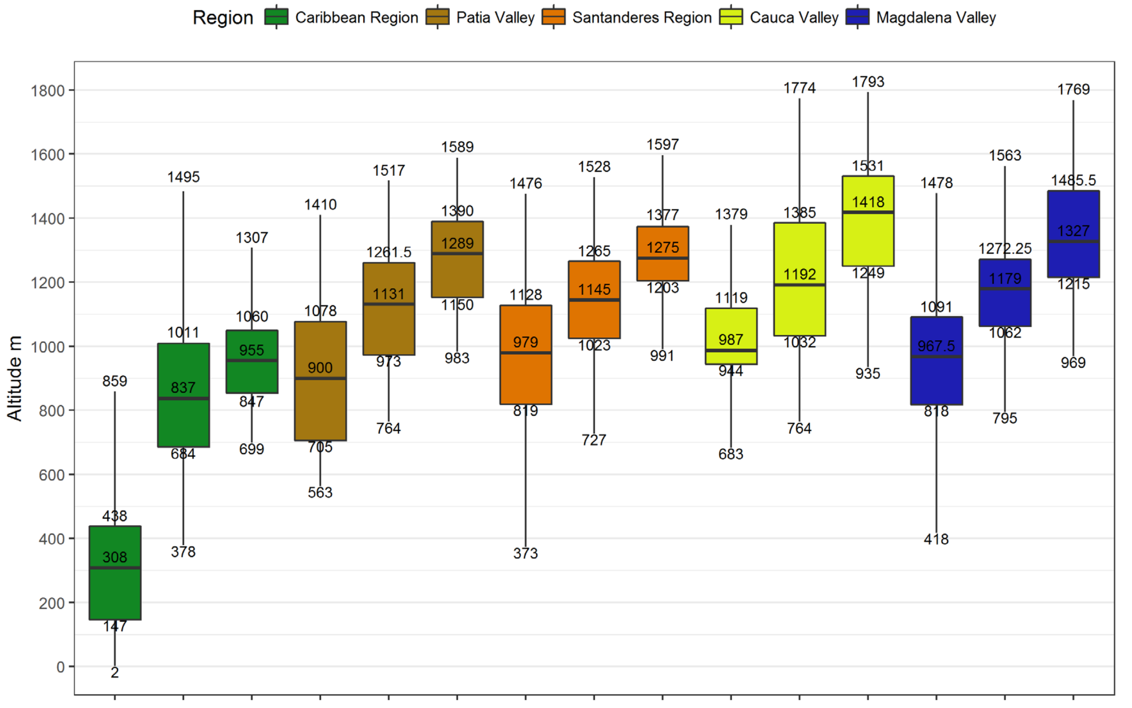

FIGURE 2. Altitudinal and temporal spectrum of suitability by bioregions for 12 species of orchids of Tropical Dry Forest (TDF) in Colombia. 1st position of the series=Present, 2nd=2030 and 3rd=2050. *Caribbean Region:* Present (*n* = 460), 2030 (*n* = 286) and 2050 (*n* = 60). *Patía River Valley:* Present (*n* = 380), 2030 (*n* = 173) and 2050 (*n* = 115). *Santander Region:* Present (*n* = 1510), 2030 (*n* = 471) and 2050 (*n* = 110). *Magdalena river Valley:* Present (*n* = 1644), 2030 (*n* = 544) and 2050 (*n* = 585). *Cauca river Valley:* Present (*n* = 6599), 2030 (*n* = 2128) and 2050 (*n* = 1482).

coincide in terms of the minimum size of suitable area (9299 ha and 9235 ha areas p>0.61 respectively see Table 4), suggesting similar dispersal patterns and possible convergent management strategies.

In a comparison of the SRES-A2 emission scenario of climate change obtained for the Cauca Valley for the 2100 period by Reina-Rodríguez *et al.* (2016) with the RCP 8.5 emission scenario used in this manuscript, the altitudinal suitability in the last quartile (25% of the data) of the SRES-A2 is between 1210 and 1470 m and is more similar to the second and third quartile (50% of the data) of the RCP 8.5, with a suitability range of 1220–1500 m for the 2050 period. Some overlap was found between the suitability of areas of the Western Cordillera and north of the Cauca River Valley; however, most of the suitability for the RCP 8.5 scenario changes from the eastern slope of the Western Cordillera to the western slope. This change is mainly attributed to the scenario used and a greater humidity on the Pacific slope than on the Cauca slope.

Figure 2 shows altitudinal suitability as a probability of occurrence for present and future conditions for orchids in the five bioregions. Fifty percent of the areas under present conditions are concentrated in the altitudinal range of 900–1100 m; however, for the 2030 climate change period, 50% of the data are concentrated between 1000 and 1300 m, with 25% between 1300 and 1700 m. For the 2050 climate change period, 50% of the data is concentrated between 1200 and 1500 m, with 25% between 1500 and 1800 m. Evidence of a shift towards higher areas of elevation in all the bioregions is evident when comparing periods.

Changes in spatial and temporal distribution —. The results of the model generated with p>0.61 project a drastic decline in suitability for orchids in all TDF areas in Colombia. The nearly 1,000,000 ha that are TDF orchids currently potential suitable area would be reduced to less than 240,000 ha during the 2050 period (see Table 5 and Figure 3).).

Table 5: Extent (ha) based on suitability (p>0.61) for orchids of the Tropical Dry Forest (TDF) in Colombia. The values are discriminated by bioregions and departments for three periods (Present, 2030 and 2050). *minimum extent.

Bioregion	Hectares			Net gain/loss (Hectares)	
	Present	2030	2050	2030	2050
Cauca River Valley					
Antioquia	13,038	19,773	18,909	6735	5871
Caldas	173	0	0	-173	-173
Quindío	28,666	5353	2245	-23,313	-26,421
Risaralda	20,032	0	0	-20,032	-20,032
Cauca Valley	493,280	166,038	106,979	-327,242	-386,301
Subtotal	**555,189**	**191,164**	**128,133**	**-364,025**	**-427,056**
Caribbean Region					
Atlantic	259	0	0	-259	259
Bolívar	2159	0	0	-2159	2159
Cesar	6476	18,737	6735	12,261	-259
Córdoba	2849	0	0	-2849	2849
La Guajira	1813	2936	86	1123	-1727
Magdalena	18,391	4576	86	-13,815	-18,305
Sucre	14,074	173	0	-13,901	-14,074
Subtotal	**46,021**	**26,422***	**6,907***	**-19,599**	**-39,114**
Magdalena Valley					
Cundinamarca	70,543	29,184	45,762	-41,359	-24,781
Huila	68,816	20,204	11,570	-48,612	-57,246
Tolima	17,700	9152*	7080*	-8548	-10,620
Subtotal	**157,059**	**58,540**	**64,412**	**-98,519**	**-92,647**
Patía Valley				0	0
Cauca	57,246	23,399	21,759	-33,847	-35,487
Nariño	7253	950*	0*	-6303	-7253
Subtotal	**64,499**	**24,349***	**21,759***	**-40,150**	**-42,740**
Santander					
North of Santander	8548	21,500	6907	12,952	-1641
Santander	130,033	28,148	6303	-101,885	-123,730
Subtotal	**138,581**	**49,648**	**13,210***	**-88,933**	**-125,371**
				0	0
Total	**961,349**	**350,123**	**234,421**	**-611,485**	**-727,187**

A reduction of 63.3% (-609,196 ha) suitability is expected for the 2030 period compared to the present, and a reduction of 75.6% (-724,878 ha) for 2050. The minimum suitability area in the Caribbean Region is 26,422 ha, and in the Patía Valley, 24,349 ha for the 2030 period. For the 2050 period, the minimum suitability for the Caribbean Region is 6907 ha; for the Santander region, 13,210 ha; and for the Patía Valley,

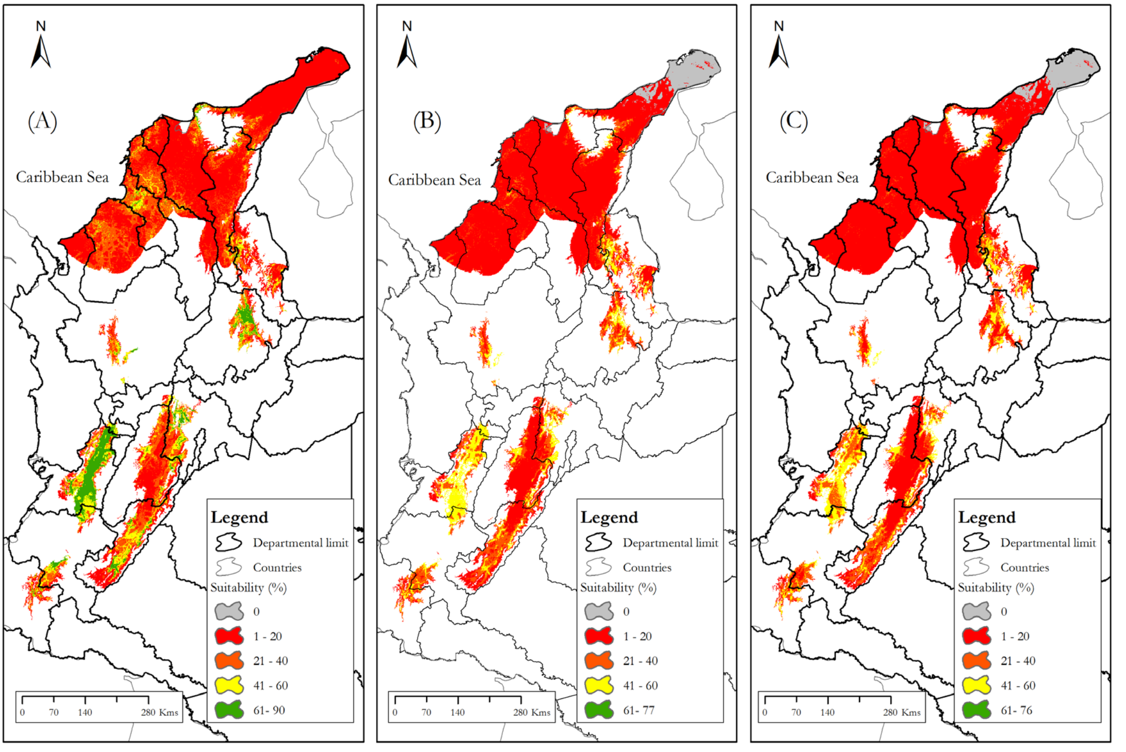

FIGURE 3. Suitability of Tropical Dry Forest (TDF) in Colombia for 12 studied orchid species. A) Present, B) 2030 and C) 2050. Red indicates areas of lower suitability and green areas of greater suitability.

21,759 ha. The values for each bioregion and the departments they comprise are shown in Table 5. The particularities and highlight events of every bioregion are discussed in Appendix 4.

Bioclimatic niches a bet for the future —. The bioclimatic niches proposed here are areas that include: a) suitable areas (p>0.61) for the future according to our model; b) areas that maintain patches of TDF within or nearby (less than 23 km); c) public or private currently protected areas (PA and NRCS) within or nearby (less than 23 km). The climatic niches would be suitable as a thermal refuges and for the altitudinal migration of flora and fauna of an area or bioregion under climate change conditions. The set of present and suitable areas, as well as the spatiotemporal ecological dynamics that occur there, would constitute this new landscape management unit. Since their inception, they are integrated into altitudinal migration corridors (AMC; see Reina-Rodríguez *et al.* 2016) and are susceptible to monitoring and management by the environmental authorities.

In Colombia, 45 basins with bioclimatic niches for the TDF ecosystem were detected at p>0.61, as shown in Table 4 and figure 4, which include 609 TDF polygons, with 52 public protected areas (PA) and 30 private protected areas (NRCS), located between 0 and 1798 m and spreading on 187,604 ha. Due to the lack of protected areas with the traits above mentioned in the Caribbean and Patía Valley bioregions, eight more areas are proposed. These areas share abiotic characteristics such as steep slopes, rock formations or relief forms that are unsuitable for agriculture and livestock, forming natural barriers for the permanent establishment of TDF cover. A total of 69 bioclimatic niches (45 net areas, 16 complementary and 8 below the threshold p=0.61) (see figure 4), based on the concept are listed in Appendix 5, and more information of interest for its management.

For the **Cauca River Valley**, 13 basins with p>0.61 for the occurrence of bioclimatic niches are proposed, which showed proximity to 239 TDF polygons, 25 PA and 23 NRCS less than 23 km away, lying within the altitudinal ranges of 629–1796 m (see Table 4 and

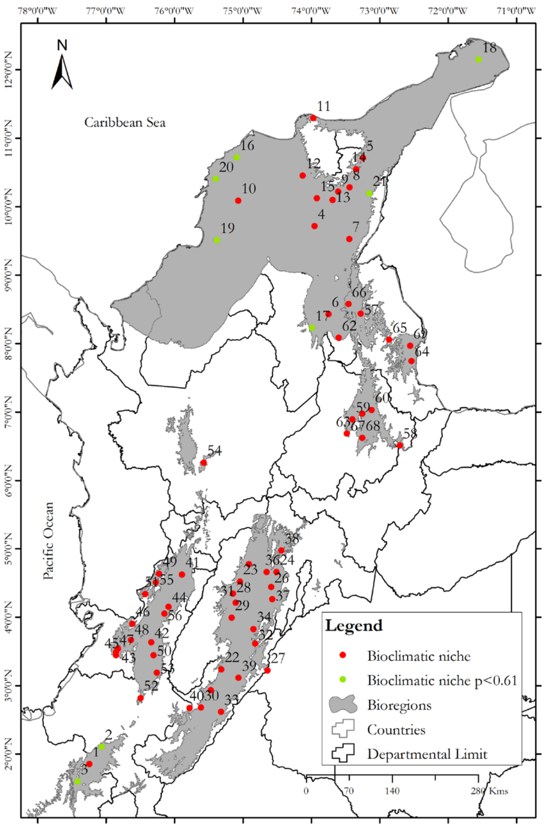

FIGURE 4. Locations of basins with the presence of bioclimatic niches and complementary areas with $p<0.61$ based on modelling of Tropical Dry Forest (TDF) orchids for the period 2050.

Appendix 3). These data target areas for management and conservation under climate change conditions. TDF orchids with narrow altitudinal distribution such as *Encyclia betancourtiana* Carnevali & I. Ramírez*, E. chloroleuca* (Hook) Neumann and *Pleurothallis aryter* Luer*,* as well as endemics or those at the maximum of their altitudinal distribution such as *Cattleya quadricolor* Lindl.*, Catasetum tabulare* and *Vanilla calyculata,* would require special monitoring under climate change.

Important areas for the future conservation of these plants will be on both slopes of the Western Cordillera and on the eastern slope of the Central Cordillera of the Cauca and Risaralda Valley, as well as on the northern flank of the Western Cordillera in the department of Antioquia (see Appendix 3). Maintaining connectivity is essential between the orchid flora of the Chocó biogeographic region and the Andes through the relict, sub-xerophytic, sub-Andean forest-dry shrubland forest existing on both slopes of the Western Cordillera, especially to conserve the richness of these plants, the existing endemics and the gene flow occurring there. New species recently described and others under study (García-Ramírez & García-Revelo 2013, Leopardi *et al.* 2014) justify management strategies and investment in conservation.

For the **Caribbean** bioregion, 8 basins are proposed with $p>0.61$ for the occurrence of bioclimatic niches, mainly along the three slopes of the Sierra Nevada de Santa Marta, with close to 91 polygons of TDF, but these polygons include no PA and only two NRCS (private areas) at less than 23 km; the altitude ranges from 0–1485 m (see Table 4 and Appendix 3). Because of the low suitability of the Caribbean bioregion, the consideration of the six areas below the established threshold of $p=0.61$ is reasonable. This would include the rolling hills and limestone cliffs up to 800 m such as the Montes de María between the Sucre and Córdoba departments, which have suitability values of $p=0.26$; the precoastal hills of the Cartagena de Indias at 170 m with $p=0.07$; the Serranía de Piojó (Atlantic) with elevations up to 350 m and $p=0.13$; the Serranía de San Lucas (Bolívar) with altitude ranging from 60–1617 m and $p=0.02$; the Serranía de Macuira with altitude up to 1000 m (Guajira) and $p=0.0$; the Serranía de Perijá (Cesar) with $p=0.03$; and the northern part of the Western Cordillera (*ex.* PNN Paramillo, Córdoba), which has a wide altitudinal range of 350–3960 m, as well as the presence of important phorophytes for orchids of the bioregion such as *Anacardium excelsum* (Bertero ex Kunth) Skeels, *Brosimum alicastrum* Sw., *Pseudobombax septenatum* (Jacq.) Dugand, *Guazuma ulmifolia*, *Samanea saman* and *Attalea butyracea* (Mutis ex L.f.) Wess.Boer (Patiño-Uribe *et al.* 2002, Sugden 1981). The presence of threatened fauna such as the cotton-top tamarin *Saguinus oedipus* L., endemic to Colombia and categorized as critically endangered (CR) (Savage & Causado 2008), demonstrates the enormous value of these areas for conservation purposes and that they have sufficient weight for being proposed as sites for bioclimatic niches in the Caribbean region. Orchids of importance in the area include *Encyclia cordigera* (Kunth) Dressler, *Cyrtopodium paniculatum* and *Trichocentrum nudum* (Bateman ex Lindl.) M.W. Chase & N.H. Williams*,* as well as others with a more restricted distribution such as *Mormodes cartonii* Hook., which would require special monitoring under climate change conditions.

For the **Magdalena Valley** bioregion, 15 basins with *p*>0.61 for the occurrence of bioclimatic niches are proposed. This is the highest value in Colombia and has 157 TDF polygons, 16 PA and four NRCS less than 23 km away and within the altitudinal range of 237–1790 m (see Table 4 and Appendix 3). Magdalena Valley has the following preferred phorophytes for orchids: *Anacardium excelsum, Attalea butyracea, Guazuma ulmifolia, Albizia guachapele* (Kunth) Dugand*, Samanea saman, Calliandra pittieri, Guarea guidonia* (L.) Sleumer*, Machaerium capote* Dugand and *Trichilia pallida* Sw. (Pizano & García 2014). The valley also has a significant number of basins with areas suitable for bioclimatic niches along both the western slope of the Eastern Cordillera and the eastern slope of the Central Cordillera. All of these basins hold the possibility of a migration event. Representative orchids in the area are *Dimerandra emarginata* (G. Mey.) Hoehne and other endemics such as *Mormodes theiochlora* (Rchb.f.) Salazar, *Trichocentrum aguirrei* (Königer) M.W. Chase & N.H. Williams*, Epidendrum mutisii* Hágsater and *E. rodrigoi* Hágsater*,* which would require special monitoring under climate change.

For the **Patía Valley**, only one basin was detected with *p*>0.61 for the occurrence of bioclimatic niches. This is the lowest value for all Colombia. The basin consists of ten polygons of TDF, and not a single PA nor NRCS are located within 23 km distance, with altitude ranging from 612–1443 m (see Table 4 and Appendix 3). Public and private protected areas are lacking, few plant inventories are available, and the State has an incipient presence at all levels.

For now, prospects for orchid conservation indicate that only natural geographic barriers exist in this territory, and these are present in specific locations with rocky massifs, which are found at the centre, north and south of the Patía Valley, showing suitability values of *p*=0.31; the dry canyons of Guáitara-Juanambú (*p*=0.32) are lower than our threshold but have steep slopes and altitudinal gradients that favour the conservation of these plants. The presence of the phorophytes preferred by orchids was recorded by our field team in these places between 500 and 1500 m; these include *Erythrina poeppigiana* (Walp.) O.F. Cook*, Ficus obtusifolia* Kunth*, Samanea saman* (Jacq.) Merr., *Guapira costaricana* (Standl.) Woodson, *Inga spectabilis* (Vahl) Willd., *Psidium sartorianum* (O. Berg) Nied., *P. guajava* L., *Calliandra pittieri* Standl., *Crescentia cujete* L., *Guazuma ulmifolia* Lam. and *Eugenia* sp. The *2013 Patía Expedition* recorded the southernmost populations of *Catasetum tabulare* Lindl., which is endemic to Colombia, and the Cauca guan *Penelope perspicax* Bangs (Class Aves, Phylum Chordata), which had not been recorded for more than 25 years in the bioregion. This demonstrates the value of these areas for conservation purposes and lends sufficient weight for these sites to be proposed as bioclimatic niches of flora and fauna in the Patía bioregion.

For the **Santander** bioregion, 8 basins with *p*>0.61 for the occurrence of bioclimatic niches were found. These niches showed proximity to 112 TDF polygons, 11 PA, no NRCS less than 23 km away and altitudinal ranges of 154–1798 m (see Table 4 and Appendix 3). The field team recorded phorophytes in the range of 730–1200 m, including *Anacardium excelsum, Machaerium capote, Guarea guidonia, Psidium guajava* L.*, Calliandra magdalenae* (DC.) Benth.*, Clusia alata* Planch. & Triana*, Hura crepitans* L.*, Crescentia cujete, Guazuma ulmifolia, Ficus insipida* Willd. and *Eugenia* sp.; endemic orchid species of TDF such as *Catasetum lucis* P. Ortiz & G. Arango*, Catasetum tricorne* P. Ortiz and *Phragmipedium manzurii* W.E. Higgins & Viveros*,* (Martínez *et al.* 2015); and birds in the IUCN threatened category such as the Blue-billed Curassow *Crax alberti* Fraser (CR), Niceforo's Wren *Thryothorus nicefori* Meyer de Schauensee (EN), and Chestnut-bellied Hummingbird *Amazilia castaneiventris* Gould (EN), among others (Donegan *et al.* 2010). The prospects for conservation of this bioregion are greater due to the existence of public protected areas, contiguity with more humid life zones (*ex*. Yariguíes National Park with continuous canopy at altitudes >1500 m) and TDF at intermediate altitudes, which increase the probability of their occurrence.

Discussion

Geographic gaps —. Large gaps of geographic information of these orchids are present in all areas of TDF in Colombia. The overlap in genera and species richness between the national listings (Pizano & García 2014) and the Cauca River Valley bioregion

Table 6: Suitability indices for the 2030 and 2050 periods in five areas of Tropical Dry Forest (TDF) in Colombia. Relative to the size of the TDF in Colombia: *IoBsT*_30 and $IoBsT_{30}$; size in the bioregion: $IoBioreg_{30}$ and $IoBioreg_{50}$; and severity: $IoShp_{30}$ and $IoShp_{50}$. Values in **bold** are higher than the average for that index.

Bioregion	$IoBsT_{30}$	$IoBsT_{50}$	$IoBioreg_{30}$	$IoBioreg_{50}$	$IoShp_{30}$	$IoShp_{50}$
Cauca River Valley	**19.9**	**13.3**	**3.4**	2.3	2.9	**4.3**
Caribbean Region	2.7	0.7	**5.7**	1.5	1.7	**6.7**
Magdalena Valley	**6.1**	**6.7**	**3.7**	**4.1**	2.7	2.4
Patía Valley	2.5	2.3	**3.8**	**3.4**	2.6	3.0
Santander Region	5.2	1.4	**3.6**	1.0	2.8	**10.5**

(Reina-Rodríguez *et al.* 2010) demonstrates that current knowledge is far from reality. The difficult logistics of collecting orchids, as well as omission by collectors who are not specialists in this group, have hindered their presence being recorded. While it is true that our data do not represent 100% of the orchids in the ecosystem, they do provide an estimate of the geographical gaps of these plants in TDF areas. There are 314 municipalities with influence in the TDF areas in Colombia. Our data for the 12 "core" species support the presence of these orchids in 118 municipalities (see Appendix 6). In other words, slightly more than half of the municipalities 196 (62,4%), do not have records, mainly the departments of Cesar, Bolívar, Atlántico, Nariño, Cauca, Caldas, Córdoba, Sucre, Huila and Cundinamarca, suggesting important geographical information gaps. Greater effort in rethinking national and regional strategies is needed to fill in these geographical gaps.

Lowland-highland altitudinal migration —. Altitudinal and latitudinal migrations have occurred during the glacial and interglacial periods; however, current extinction rates are 1000 times the background rate (Pimm *et al.* 2015). A progressively warmer climate would induce these plants to migrate, probably vertically from low-lying areas to higher areas (Foster 2001). Recent studies support this hypothesis in Peru (Feeley *et al.* 2011, Lutz *et al.* 2013), Venezuela (Safont *et al.* 2012) and Colombia (Reina-Rodríguez *et al.* 2016). The data herein supported estimates of altitudinal changes of 177.5 m (present–2030) and 379.8 m (present–2050) for the 12 focal species. In the case of TDF orchids, the greatest impediment to ascending the mountains is the availability of suitable habitat due to habitat fragmentation, land use and the extraction of phorophytes in mid-mountain areas. Undoubtedly, this condition limits the dispersal of orchids from lowland areas. The possibilities of success and responses to thermal (low altitude) and water stress may vary according to the degree of specialization that varies between species (Laurance *et al.* 2011, Stevens 1992, Hsu *et al.* 2014, Reina-Rodríguez *et al.* 2016) and the intrinsic resistance capabilities linked to their evolutionary history (Darwin 1872). Further studies focused on genotypic and physiological responses of these plants would be desirable in the short term. Preventive measures are urgently required due to the limited availability of habitat and land use in the mountainous areas north of the Andes (Young & Lipton 2006). The assemblage between bioclimatic niches (BN) proposed here and Altitudinal Migrations Corridors AMC, planned dispersal routes that connect forest relics through a gradient of thermal, edaphic, and moisture and will play an important role in the adaptation and altitudinal displacement of orchids caused by Climate Change (Reina-Rodríguez *et al.* 2016). The establishment of AMC, included the enrichment and management of phorophytes and the use of protective riverine forest of 30 m or more (Law 1449/1977). It also covered public protected areas (PA), such a Natural Parks, and private protected areas such as Natural Reserves of Civil Society (NRCS) stipulated in Colombian legislation (Law 2372/2010); all of these are included in the National System of Protected Areas (NSPA, in Spanish SINAP). These areas would function as nodes of altitudinal connectivity and are fundamental units of the landscape to facilitate orchid dispersal. The spatiotemporal dynamic and interspecific relationships of biodiversity have recurrently been ignored. However, we in section 4.4 have analyzed some complementary factors not included in the current models.

Where will the orchids be found in the future? —. The areas and associated maps show a drastic reduction in areas of suitability due to climate change in the two periods and the five bioregions examined. The loss of suitable areas is especially evident in the Caribbean, the Santander and the Patía River Valley regions as shown in Figure 1. However, in terms of extent, the IoBsT index (see Table 6, available only electronically as supplemnetal material at: http://www.lankesteriana.org/Lankesteria-naJournal/17(1)/reina%20rodriguez%20et%20al%202017%20appendix6.pdf), identifies the Cauca River Valley as the bioregion with the greatest loss of suitability for both future periods, showing reduction to one-quarter (1/4) of its present size, while the IoBioreg index shows that the most significant regional losses will occur inside the Caribbean region, which will be reduced to one-sixth (1/6) of its present extent. However, the IoShp index shows that change will occur with the greatest severity in the Santander region, where the area will be reduced to one-tenth (1/10) of the present area. The minimum suitability values suggest that the Caribbean and Patía Valley bioregions are the most critical in the country.

Suitability for the 2050 period will disappear from the following departments: the Atlantic, Bolívar, Sucre and Córdoba departments in the Caribbean bioregion; the department of Nariño in the Patía Valley bioregion; and the department of Risaralda in the Cauca River Valley bioregion. Meanwhile, the Cauca Valley department of the Cauca River Valley bioregion, the Cundinamarca department of the Magdalena Valley bioregion and the Cauca department of the Patía Valley bioregion will maintain the highest suitability for this period.

Results from the model suggest that many areas, especially from the Caribbean Plains and the Patía Valley, will not be suitable following the changes that lie ahead (see Appendix 3). Flat areas below 600 m without elevation gain within 50 km of populated centres of more than 50,000 inhabitants are characteristics that may lead to the eventual loss of suitability in the next 50 years. Temperature increases, decreased water availability, and the long distances required for migration to higher altitudes are all risk factors for the survival of these plants. Greater efforts and national conservation strategies of TDF should focus on these areas, specifically in the basins and complementary areas shown in Appendix 3.

Bioclimatic niches, pollinators and mycorrhizae —. The spatiotemporal dynamic and interspecific relationships of biodiversity have recurrently been omitted in previous studies. Biotic and abiotic factors exist at the margins of the current tools being used and are worth considering when preparing the new generation of models with greater biological realism, which will include interactions, types of dispersion and evolutionary patterns that will improve the accuracy of predictions (Urban 2015). This study evaluated several factors for assigning bioclimatic niches *a posteriori* as a landscape management unit and as a new spatiotemporal management strategy.

According to the database of Insect Collection of the Museum of Entomology of the Valley University (2013), available at http://ipt.sibcolombia.net/valle/resource.do?r=insectos-universidad-del-valle, insect pollinators are present in TDF areas of Colombia across wide altitudinal gradients from 0–2800 m, favouring cross-pollination and dispersal processes. These pollinators can travel up to 23 km in the five bioregions, which include 609 TDF polygons, 52 public protected areas (PA) and 30 private protected areas (NRCS) that are located between 0 and 1798 m on 187,604 ha distributed in 45 basins throughout the country; thus, the potential exists for this proposal to be feasible throughout the country. Nonetheless, some areas at altitudes below the threshold generated by the model had abrupt relief-forming natural barriers that prevent the establishment of urban areas, mechanized agriculture or other types of exploitation. This condition allows the establishment of plant cover that creates a microclimate suitable for the establishment of the phorophytes, mycorrhizae, pollinators and dispersers necessary for the occurrence of Orchidaceae. Populations of *Catasetum tabulare* with fruits were observed in the pyroclastic massifs in the north-east and centre of the Patía Valley, confirming the presence of these pollinators and the quality of the ecosystem. In the Caribbean bioregion, areas with these characteristics are also present in the precoastal hills close to Cartagena de Indias (100 m), Serranía del Piojo, Serranía de Macuira (735 m), Serranía de San Lucas (1617 m) and Montes de María (570 m), making their inclusion as bioclimatic niches acceptable, given the absence of protected areas in these bioregions.

Little is known about the survival of mycorrhizal fungi and their spatiotemporal variations when faced with an increase in average temperature in Colombia of 2.6°C. However, physiognomically well-structured and conserved forests greater than 10 ha can be assumed to have a microclimate suitable for containing the mycorrhizae necessary for orchid germination. The presence of at least three of the major phorophytes of these plants (see Table 2) was corroborated in the field in 25% of the bioclimatic niches presented here.

Conclusions and recommendations

In this paper we provide a complementary vision based on the presence of living organisms that are intrinsic parts of the ecosystem. The results suggest a significant loss of areas of suitability due to climate change by bioregions and periods (present–2030, present–2050 and 2030–2050). The Santander region, the Caribbean region and the Cauca River Valley will lose much of their present extent of suitability. An altitudinal displacement, which was not uniform, was also detected in the five studied bioregions. Foothills with altitudes of 1165.4 SD±222.6 will have greater suitability for the 2030 period, and the areas of foothills with altitudes of 1364.1 SD±195.1 will have greater suitability for the 2050 period.

In this sense, the model results reinforce the hypothesis of migration of TDF orchids in the northern part of South America, where there has been an increase in altitudinal suitability of the orchids of TDF lowlands towards the mid-mountain areas in the Colombian Andes.

Euglossini bees, vectors of cross-pollination in orchids, are present in both TDF areas and in moist forests at a wide range of altitudes. Their ability to thermoregulate and fly long distances even in dry environments is one of the key biotic elements that enable this altitudinal migration.

The results highlight the importance of articulating complementary spatiotemporal dynamic conservation strategies compared to current and static protected areas. Herein, a new landscape management unit *bioclimatic niche* was defined, which combines the current ecologically valuable coverages of ecosystems and their future areas of suitability. Several biotic and abiotic variables not collected for the actual generation of models have been included in the analysis. In total, 69 areas were proposed as bioclimatic niches, becoming the first national approximation to use living organisms to complement technical criteria in decision-making for land-use planning under climate change conditions. The identification of these bioclimatic niches serves as an early warning for focusing resources and efforts on these areas and altitudinal ranges. In the short term and at a detailed scale, design, implementation and articulation are required between the bioclimatic niches proposed here and supported by the model with AMC and the public and private protected areas in TDF in Colombia. The inclusion of some areas with $p<0.61$ and abrupt relief are the only guarantee of conservation of orchids in the Caribbean region, and the Patía Valley is equally important, where the absence and low representation of orchids are evident. In terms of land-use management, bioclimatic niches should be included within restoration-reforestation plans, land-use plans (LUP), watershed management plans (WSMP) and approaches such as ecosystem-based adaptation (EbA) referred to in the national climate change policy. This task should be specifically undertaken in the short term by the regional autonomous corporations throughout Colombia as an adaptation measure to safeguard biodiversity.

The regional environmental authorities and agencies for the conservation of nature of the national and international order, as well as NGO's and local communities, are key actors in considering, implementing and adjusting the implementation of the conclusions supported herein and currently underway. Finally, evidence shows large geographical gaps of orchids in this ecosystem, especially in the Patía Valley, Caribbean region, and south of the Magdalena Valley, as well as in the inaccessible dry enclaves. However, new knowledge of their geographical distributions is becoming available through infrastructure projects established by the Colombian legislature.

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APPENDICES

Appendix 1. Species of orchids selected for modelling, their distribution in departments in Colombia, altitudes and notes on their ecology.

Species	Distribution	Supplemental notes
Brassavola nodosa (L.) Lindl.	Neotropical; (Bol, Col, CR, Ecu, Guy, Mex, Per) Col: (Ant, San, Bol, Cal, Ces, Cor, Cho, Cun, Gua, Mag, San, Suc, Tol) 5-950 m.	Rounded and succulent leaves to store water and prevent dessication. Grows in open areas exposed to light. Grows in dry forests and sub-xerophytic shrubland. Phorophytes: *Caesalpinia punctata, Caesalpinia tortuosa, Pereskia guamacho, Samanea saman, Crescentia cujete* and *Anacardium excelsum.*
Catasetum tabulare Lindl.	Endemic; (Col) 200-1350 m. Col: (Ant, Ris, VdC, Tol, Suc)	Equipped with pseudobulbs up to 25 cm in length to store water. Prefers perimeter areas of dry forest and riverine forests with medium brightness. It has been observed in living fences and at the perimeters of abandoned coffee plantations, as well as in groups of trees outside the forest but sheltered from the wind. It grows on *Gliricidia sepium, Senna spectabilis, Anacardium excelsum, Machaerium capote* and *Brosimum alicastrum.*
Cyrtopodium paniculatum (Ruiz & Pav.) Garay	Neotropical; (Bol, Col, CR, Ecu, Guy, Mex, Per) Col: (Ant, Cor, Bol, Cau, Ces, Cun, Mag, Hui, San, Suc Vch, VdC) 5-1200 m.	Equipped with pseudobulbs up to 60 cm in length to store water. Grows in dry forest and sub-xerophytic dry shrubland and as a terrestrial plant in outcrops of sedimentary rocks in foothill areas with frequent wildfire, despite which this species persists. As an epiphyte, it has been observed on *Anacardium excelsum*, *Sterculia apetala* and *Elaeis guineensis*.
Dimerandra emarginata (G. Mey.) Hoehne	Neotropical; (Bel, Bra, CR, Ecu, Sal, GFr, Gua, Guy, Hnd, Mex, Nic, Pan, Per, Sur, Ven) Col: (Ant, Ara, Bol, Cal, Cas, Cau, Ces, Cun, Gua, Mag, Met Qui, Ris, San, VdC) 100-1400 m.	Possesses elongated pseudobulbs up to 40 cm in length. It grows in lowlands and Andean foothills and is present in dry forests, sub-xerophytic shrubland and seasonally flooded forests, including wooded pasture. Populations present in the Cauca River Valley occupy the altitudinal ceiling of the continent. It has been observed on *Anacardium excelsum, Erythroxylum ulei, Ficus insipida, Xylopia ligustrifolia, Laetia americana* and *Oreopanax cecropifolius.*
Epidendrum rigidum Jacq.	Neotropical; (Arg, Bel, Bol, Bra, Bhm, Cub, Rdm, Jam, PR, Tri, Col, CR, Ecu, Gua, Guy, Hnd, Mex, Nic, Pan, Per, Sur, Ven) Col: (Ant, Boy, Cal, Cau, Cun, Hui, Nsa, Mag, Ris, San, Qui, VdC) 600 -1355 m.	Has waxy cuticle as an adaptation to the conditions of water stress. Grows in dry forest, seasonally flooded forests, riverine forests and forest-pasture perimeters in areas of high and medium brightness. It has been observed on *Anacardium excelsum, Laetia americana, Luehea seemannii, Guarea guidonia, Erythroxylum ulei, Guarea kunthiana, Chlorophora tinctoria* and *Ficus obtusifolia.*
Jacquiniella globosa (Jacq.) Schltr.	Neotropical; (Bel, Bol, Bra, Col, CR, Cub, Ecu, GFr, Gua, Guy, Hnd, Jam, Mar, Mex, Nic, Pan, Per, PR, RD, Sal, Sur, T&T, Ven) Col: (Ant, Cho, Cau, Cun, Gua, Hui, Mag, Met, Qui, Ris, San, VdC) 700-1600 m.	Small epiphyte with rounded leaves and thick cuticle. Grows in riparian forests, sub-xerophytic shrubland and seasonally flooded forests. Establishes both on the exterior branches of shrubs a few metres from the ground and in treetops more than 30 metres high. It has been observed on Ficus insipida, *Lonchocarpus* sp., *Anacardium excelsum*, *Neea divaricata*, *Clusia minor, Zanthoxylum fagara* and *Clusia fructiangusta.*
Oeceoclades maculata (Lindl.) Lindl.	Subcosmopolitan; (Arg, Bol, Bra, R. Dom, Jam, PR, Col, Com, CR, Ecu, El Salv, Gua, Guy, Hnd, Mex, Pan, Par, Per, Sur, Tan, Ven) Col: (Ant, Bol, Cal, Cas, Cau, Ces, Cor, Cun, Mag, Nsa, VdC, Ris, San, Suc, Tol.) 20-1150 m.	Only terrestrial species, occasional epiphyte. Possesses underground succulent pseudobulbs for water storage. Extensive global distribution occurring in both the Paleotropics and Neotropics. Grows in dry forests dominated by *Anacardium excelsum, Sabal mauritiiformis, Syagrus sancona* and *Attalea butyracea* in transition areas between pasture and riparian forest. This adaptation to different ombro climates has enabled its colonization to different environments around the world.
Polystachya foliosa (Hook.) Rchb. f.	Neotropical; (Arg, Bel, Bol, Bra, Cub, Rdm, Jam, PR, Col, CR, Ecu, Sal, Gua, Guy, Hnd, Mex, Nic, Pan, Par, Per, Sur, Ven) Col: (Ant, Ara, Boy, Cal, Cas, Cau, Cun, Guaj, Mag, Met, Nsa, Qui, Ris, San, VdC, Vich) 50 -1400 m.	Possesses small oval pseudobulbs to store water. Grows at perimeters of riverine forests and seasonally flooded forests. More abundant below 500 m. It has been observed on *Laetia americana, Guarea guidonia, Vitex orinocensis, Inga spectabilis* and *Miconia* sp.

Appendix 1 (*continues*).

Species	Distribution	Supplemental notes
Scaphyglottis prolifera (R. Br.) Cogn.	Neotropical; (Bel, Bol, Col, CR, Ecu, Gua, Guy, Hnd, Jam, Mex, Nic, Pan, Per, Tri, Ven). Col: (Ant, Cau, Cho, Cun, Gua, Hui, Mag, Met, Ris, San, VdC) 500-1600 m.	Possesses multiple elongated and plump pseudobulbs to prevent dessication. Grows in riparian forests, sub-xerophytic shrubland and forest perimeters or at the interior of forests with neighbouring areas of pasture. In localities with semi-arid climate, this plant finds refuge in the depressions of water channels where the microclimate is more humid. It has been observed on *Brosimum alicastrum, Matisia* sp., *Guarea guidonia, Anacardium excelsum, Guazuma ulmifolia, Amyris pinnata, Daphnopsis americana, Aegiphila grandis, Machaerium capote, Guarea guidonia, Hura crepitans, Erythroxylum ulei, Luehea seemannii, Laetia americana and Dendropanax colombianum.*
Trichocentrum carthagenense (Jacq.) M.W. Chase & N.H. Williams	Neotropical; (Bel, Col, CR., Gua, Hnd, Mex, Nic, Pan, Sal, Ven.) Col: (Ant, Ara, Bol, Boy, Cas, Cau, Cor, Cun, Gua, Hui, Mag, Met, Boy, Tol, Mag, San, Suc, VdC, Vic) 50-1200 m.	Waxy cuticle for adaptation to conditions of water stress. Grows in dry forest and in flooded and non-flooded habitats, sub-xerophytic shrubland, and riverine forests. Frequently epiphytic on trunks and stems a few metres from the ground and less often in matts of leaf litter and decaying trunks. It has been observed on *Eugenia bicolor, Anacardium excelsum, Citharexylum kunthianum, Eugenia monticola, Neea divaricata, Ardisia guianensis, Guazuma ulmifolia, Calliandra* sp., *Jacaranda obtusifolia, Maclura tinctoria* and *Machaerium capote.*
Trizeuxis falcata Lindl.	Neotropical; (Bol, Bra, Col, CR, Ecu, Pan, Per, Ven). Col (Ant, Ara, Boy, Caq, Cas, Cau, Cun, Met, Mag, VdC, Qui, Ris, San) 100-1500 m.	Small pseudobulbs and flattened leaves reduce the effect of the wind to minimise dessication. Frequent on fences, trunks, roadsides, and citrus trees and always found in environments of bright light and with a high level of recruitment. Rarely found at the interior of the forest. It has been observed on *Psidium guajava, Citrus* spp., *Crescentia cujete, Parathesis reticulata, Coffea arabica, Guapira costaricana* and *Eugenia* sp.
Vanilla calyculata Schltr.	Neotropical; (Col, Hnd, Mex, Sal) Col: (Hui, Mag, Nar, Tol, VdC) 570 -1200 m.	Possesses creeping habit and swollen stalks with greater capacity to store water and prevent desiccation. Grows in foothills of the Central Cordillera and Western Cordillera in dry and sub-xerophytic habitats, as well as in alluvial deposits of the inter-Andean valleys. It has been observed on *Cupania americana, Eugenia monticola* and *Psidium sartorianum.*

Country abbreviations: **Arg**: Argentina; **Bel**: Belize; **Bhm**: Bahamas; **Bol**: Bolivia; **Bra**: Brasil; **CR**: Costa Rica; **Col**: Colombia; **Cub**: Cuba; **Ecu**: Ecuador; **Gua**: Guatemala; **Guy**: Guyana; **GFr**: French Guyana; **Hat:** Haiti; **Hnd:** Honduras; **Jam**: Jamaica; **Mex**: Mexico; **Nic**: Nicaragua; **Pan**: Panama; **Per**: Peru; **RD**: Dominican Republic; **Sal**: El Salvador; **Sur**: Surinam; **T&T**: Trinidad& Tobago; **Urg**: Uruguay; **PR**: Puerto Rico; **Par**: Paraguay; **Ven:** Venezuela. Abbreviations of departments of Colombia: **Ama**: Amazonas; **Ant**: Antioquia; **Ara**: Arauca; **Atl**: Atlantic; **Bol:** Bolívar; **Boy:** Boyacá **Cal:** Caldas; **Caq**: Caquetá; **Cau**: Cauca; **Cas:** Casanare; **Ces**: Cesar; **Cho**: Chocó; **Cor**: Córdoba; **Cun**: Cundinamarca; **Guai**: Guainía; **Guav**: Guaviare; **Guaj**: La Guajira; **Hui**: Huila; **Mag**: Magdalena; **Met**: Meta; **Nar**: Nariño; **Nsa**: North of Santander; **Put**: Putumayo; **Qui**: Quindío; **Ris**: Risaralda; **San**: Santander; **Sap**: Sán Andrés and Providencia; **Suc**: Sucre; **Tol**: Tolima; **VdC**: Valle del Cauca; **Vau**: Vaupés; **Vich:** Vichada.

Appendix 2. Kappa value according to Monserud and Leemans (1992).

Kappa Value	Estimation
K <0.05	No agreement
0.05 ≤ K <0.20	Very poor
0.20 ≤ K <0.40	Poor
0.40 ≤ K <0.55	Medium
0.55 ≤ K <0.70	Good
0.70 ≤ K <0.85	Very good
0.85 ≤ K <0.99	Excellent
0.99 ≤ K ≤100	Perfect

Appendix 3. Variance Analysis of one factor.

Summary

Groups	*Count*	*Sum*	*Mean*	*Variance*
Presente	10213	10041305	983,1885832	54291,62268
2030a	3429	3996036	1165,364829	49544,98559
2050b	2237	3051427	1364,071077	38030,01239

Variance Analysis

Origin of variations	*Sum of squares*	*Degrees of freedom*	*Average of squares*	*F*	*P* Value *Probability*	Critical value for F
Between groups	300995377,6	2	150497688,8	2952,301082	0,0000	2,996297626
Within groups	809301369,1	15876	50976,40269			
Total	1110296747	15878				

APPENDIX 4. Highlights for adaptation to climate change in five Tropical Dry Forest (TDF) bioregions in Colombia.

Bioregion	Number of orchids	Spatiotemporal changes according to the model	IDEAM Prediction	Highlights
Cauca River Valley	70 species (Reina-Rodríguez *et al.* 2010)	Loss of suitability areas, especially north of the Department of Cauca, Cauca Valley, to Risaralda along the floodplain of the Cauca River; see Table 4. Compared to other bioregions, it loses the largest area of suitability and does so consistently in the two periods and = 13.3). These changes will be more pronounced in the short term = 3.4) than in the medium term = 2.3). The severity will be more pronounced in this last period with above average values (4.3); see Table 5. Suitability increased only in Antioquia for both the 2030 and 2050 periods, attributed to an increase of 9.3% in precipitation.	Temperature will increase by 2.4 degrees, and precipitation will only increase at the limits of the department of the Valle del Cauca and the department of Risaralda.	The northern area of this bioregion hosts the largest relicts of TDF and is where most of the orchid richness is maintained. The implementation of conservation action in the short and medium term is vital. The loss of suitability in areas of connectivity of the Dagua and Cauca basin, which is consistent in the two periods with $p \leq 20$, is of great concern, as seen in Figure 3. Attention-investment should be in design actions and implementation of AMC. AMC are high priority.
Caribbean Region	53 species at altitudes < 1000 m. (Betancur *et al.* 2015)	More than any other bioregion, suitability areas in the Caribbean region are especially low ($p \leq 20$) and marked on maps; see Figure 3. Suitability areas will be lost in both the 2030 and 2050 periods. Changes in this bioregion will be more pronounced in the short-term = 5.7) than medium-term = 1.5). Severity will be greater in the second period, with values greater than average > see Table 5.	10-30% less precipitation and an average annual temperature of 30°C are predicted.	The minimum values detected by the model for both periods (26,422 ha and 6907 ha) are critical values compared to other TDF areas in Colombia. For the 2050 period, suitable areas disappear in departments such as Córdoba, Sucre, Bolívar and Atlantic. Orchids present here will be more exposed to hydric and thermal stress, especially in the large flat areas without altitudinal gradients. Areas with strong slopes, cliffs and areas unsuitable for mechanized agriculture and urbanization become important (Macuira, Snia. Piojó, Montes de María, precoastal hills to Cartagena). Attention-investment in knowledge of orchid biodiversity and conservation activities is high priority.
Magdalena Valley	73 species in the Magdalena Valley (Bernal *et al.* 2015)	At the national level, this bioregion loses the second-most area of suitability after the Cauca River Valley; see Table 4. It is consistent in both periods and = 6.7), especially the departments of Huila and Cundinamarca in both periods. The department of Tolima will have minimum areas of regional suitability in both periods; see Table 1. Bioregional indices are above average = 3.7 and =4.1), but particularly notable is the medium-term value, which exceeds that of the other bioregions in Colombia, for which it is expected that the effect on biodiversity will be greater during this period; see Table 5.	Increases of 2.7°C in temperature, and between 20% and 30% in precipitation are expected, especially towards the southern part.	The Magdalena Valley has extensive flat areas, but unlike the Caribbean region, it has thermic/altitudinal gradients less than 50 km away. In this regard, the prospects for orchid conservation in the mid-basin of the Magdalena river are greater. The basins of the inner slopes of the Central and Eastern cordillera acquire great relevance for conservation. Attention-investment in knowledge of orchid biodiversity activities in the central and southern area of this bioregion is high priority. The design and implementation of AMC is a priority.
Patía Valley	< 30 species (Reina-Rodríguez *com pers.*)	Losses of suitable areas are expected in both periods. The indices calculated show values above average in both periods =3.8 and =3.4), also suggesting significant changes in size, with the greatest intensity in the short-term. The severity will be more pronounced than other areas of the country	Precipitation will increase 10-30%, and temperature will increase by up to 2.4°C.	The model detected minimum values in suitability areas for the two periods (26,422 has and 6907 has). The department of Cauca will lose the largest suitable area, and suitable areas would disappear from Nariño; see Table 4. The Patía Valley has thermic/altitudinal gradients at less than 50 km, which facilitate the design and establishment of AMC. During the field phase, areas with cliffs and concave rock formations up to 760 m. were observed, which contain TDF vegetation and where the flora and fauna found refuge against a warmer and more exposed environment. Other territories to the south have relief with steep slopes that form natural barriers on the inner slopes of the Central-Western Cordillera. Some of these areas have been proposed as climatic niches.

Appendix 4 (*continues*).

Bioregion	Number of orchids	Spatiotemporal changes according to the model	IDEAM Prediction	Highlights
Santander Region	127 species (Martínez *et al.* 2015)	Loss of areas of suitability is expected for both periods. The severity index for the 2050 period has the highest value of the country =10.5). Therefore, stronger and higher changes than any other TDF area are expected (see Figure 4). The minimum value of 13,210 ha for the 2050 period along with the Patía Valley and the Caribbean region is one of the lowest for this period	Thermic increases of 2.7°C and hydric decreases of 10% to 40% are predicted for the end of the century, which could affect the ecosystem simultaneously.	The Santander territory, as well as other areas, has large steep areas on the western slope of the Eastern Cordillera that connect the Andes with altitudinal gradients from the Magdalena River to areas of páramo (100-3400 m.a.s.l.). It is the only bioregion with large TDF areas located in mid-mountain areas, a factor that could facilitate migration routes more quickly in this bioregion than in other areas. Attention-investment in in the design and implementation of AMC is high-priority.

Appendix 5. Location of bioclimatic niches in Colombia for adaptation-conservation. Based on the modelling of Tropical Dry Forest (TDF) orchids for 2050 under Climate change scenario. In **bold** are complementary areas with p<0.61. Abbreviations: PA = Public proctected areas; NRCS = Natural Reserves of Civil Society (private protected areas); S.N.S.M= Sierra Nevada de Santa Marta

Id.	Bioregion	Basin (s) and/or Areas with	Mountainous System/ Cordillera	Slope	Municipalities	(a) Areas with net suitability $p > 0.61$ (ha)	(b) Areas of TDF < 23 km (ha)	(c) Areas of PA < 23 km (ha)	(d) Areas of NRCS < 23 km (ha)	Altitudinal range (a-b); (a-c); (a-d)	% of suitable area in the basin	Environmental authority
1		Direct to Cauca	Western C.	East-West	Medellin, Ebéjico, San Jerónimo, Heliconia	50074	22988	10308	82	460-1791	2.04	CVC-CRC
2		Amaime	Central C.	West	El Cerrito, Palmira	4398				1026-1775	5.53	CVC
3		Anchicayá	Western C.	East	Buenaventura, Dagua			23765		629-1789		CVC
4		Bugalagrande	Central C.	West	Bugalagrande, Andalucía, Tuluá	3386	370			1017-1128	4.93	CVC
5		Cajambre	Western C.	East	Buenaventura			2201		1131-1692	5.62	CVC
6		Calima	Western C.	East	Calima, Restrepo, Yotoco	8864	119		141	1544-1619	12.60	CVC
7		Cuenca	Western C.	East	Buenaventura			20164		697-1771	0.17	CVC
8	Cauca River Valley	Dagua	Western C.	East	Dagua, Restrepo, Yotoco, Vijes, Calima	16234	2179	15015	343	649-1796	6.36	CVC
9		De Las Vueltas	Western C.	East	El Cairo, Versalles, El Dovio, Bolívar	7284	417		298	1096-1466	2.29	CVC-CODECHOCO
10		Fraile	Central C.	West	Palmira, Florida, Pradera	1537	41	608		948-1752	1.76	CVC
11		Garrapatas	Western C.	East	Bolívar, Trujillo	1249	395			920-1254	2.73	CVC

12		Ovejas	Central C.	West	Caldono, Piendamó	1284				1521-1570	1.10	CVC-CRC
13		Paila	Central C.	West	Miranda, Corinto, Florida	1341				1248-1576	4.66	CVC
14		Porce	Western C.	North	Itaguí, Medellín, Sabaneta	13480		507		1472-1791	0.07	CORANTIOQUIA
15		Sipi (Garrapatas)	Western C.	East	El Dovio	81	656		11	804-1140	5.34	CVC
16		Tuluá	Central C.	West	Andalucía, Tuluá, San Pedro	6044	946		70	958-1374	0.05	CVC
17		Ariguaní	S.N.S.M.	West	Pueblo bello	880	1808			249-846	0.22	CORPOMAG
18		Badillo	S.N.S.M.	East	Valledupar	168	8138			147-992	0.27	CORPOCESAR
19		Catatumbo	Eastern C.	East	Río de Oro	169	1717			1214-1485	0.48	CORPONOR
20		Cesar	S.N.S.M.	East	Manaure balcón del Cesar, Valledupar	502	33048		373	118-1337	0.07	CORPOCESAR
21		Cesarito	S.N.S.M.	East	Pueblo bello, Valledupar	314				782-1095	0.26	CORPOCESAR
22		Dilubio	S.N.S.M.	East	Valledupar		82			507-736		CORPOCESAR
23		Direct to Magdalena	Central C.	North	Río de Oro	169	5475			83-829	0.17	RACDIQUE
24		Direct to Caribe	S.N.S.M.	North	Santa Marta	62	12156		72	0-535	0.06	CORPOCARIBE
25		Fundación	S.N.S.M.	West	Aracataca		28			867-962		CORPOMAG
26		Garupal	S.N.S.M.	East	Valledupar, El Copey		10146			308-1194		CORPOCESAR
27	Caribbean Region	Guatapurí	S.N.S.M.	East	Valledupar	2492	1053			196-730	3.19	CORPOCESAR
28		Mallorquin	S.N.S.M.	West	El Copey		2785			322-1083		CORPOCESAR
29		**Snia. Piojó**	Isolated hills	All	Luruaco, Piojó							CRA
30		**Snia. San Lucas**	Isolated hills	All	San Jacinto del Cauca, Simití, Sta Rosa							CARDIQUE
31		**Snia de Macuira**	Isolated hills	All	Uribia							CORPOGUAJIRA
32		**Snia. Montes De María**	Isolated hills	All	S. J. de Nepomuceno, S. Jacinto, El carmen de Bolivar, Ovejas, Los Palmitos, Morroa, S. Onofre, Chalán, Toluviejo, Colosó							CARSUCRE
33		**Colinas prelitorales Cartagena de indias**	Isolated hills	All	Cartagena de Indias, Turbaco, S.ta Rosa, S.ta Catalina							CARDIQUE
34		**Snia. Perijá**	Eastern C.	West	Urumita, Manaure, Agustin Codazzi, Becerril, La Jagua de Ibirico, San Diego							CORPOCESAR

Appendix 5 (*continues*).

Id.	Bioregion	Basin (s) and/or Areas with	Mountainous System/ Cordillera	Slope	Municipalities	(a) Areas with net suitability $p > 0.61$ (ha)	(b) Areas of TDF < 23 km (ha)	(c) Areas of PA < 23 km (ha)	(d) Areas of NRCS < 23 km (ha)	Altitudinal range (a-b); (a-c); (a-d)	% of suitable area in the basin	Environmental authority
35	Magdalena River Valley	Aipe	Central C.	East	Neiva	173	52			702-776	0.16	CAM
36		Alvarado	Central C.	East	Ibagué		23			724-757		CORPOTOLIMA
37		Apulo	Eastern C.	West	Cachipay, La Mesa, Tena, Anolaima, Zipacón	6675	4935			518-1548	12.36	CAR
38		Bache	Central C.	East	Neiva, Palermo, Santa María	5544	1102			554-814	3.76	CAM
39		Bogotá	Eastern C.	West	El Colegio, Tequendama, La Mesa, Tena	2973	8233	323		335-1751	0.61	CAR
40		Cabrera	Eastern C.	West	Alpujarra	1172	9533	5800		368-1621	0.48	CAM
41		Coello	Central C.	East	Ibague	85	180	134		693-1108	0.05	CORPOTOLIMA
42		Direct to Magdalena	Central C.-Oriental	East-West	Tello, Neiva, Rivera, Dolores, Prado, Guaduas, S.J. Rioseco, Chaguaní	7445	26814	20864		200-1797	0.17	CORMAGDALENA
43		Iquira	Central C.	East	Íquira	249				1077-1132	0.56	CAM
44		Luisa	Central C.	East	Valle del San Juan		5			638-660		CORPOTOLIMA
45		Negro	Eastern C.	West	Caparrapí, Villeta, Guaduas, Pacho, Chaguaní, Dolores	3570	750	163	10	418-1207	11.22	CORPOTOLIMA
46		Neiva	Eastern C.	West	Riverar, Algeciras, Campoalegre	536	4508			495-1530	0.48	CAM
47		Prado	Eastern C.	West	Pardo, Icononzo, Melgar		2913	87		307-1324		CORPOTOLIMA
48		Recio	Central C.	East	Ambalema		96			237-737		CORPOTOLIMA
49		Seco	Eastern C.	West	S.J. Rioseco, Anolaima	1025	1460			378-1298	1.69	CAR
50		Sumapaz	Eastern C.	West	Tibacuy, Fusagasugá, Arbelaez, Silvania	7842	3242	2339	1	305-1744	2.37	CAR
51		Tobia	Eastern C.	West	Villeta, Quipile, Sasaima, La Vega, San Francisco, Nocaima, Vianí, Bituima, Anolaima, Albán, Guayabales de Síquima	11512			2	966-1790	13.48	CAR
52		Villa Vieja	Eastern C.	West	Tello	165		3606		428-775	0.18	CAM
53		Yaguará	Central C.	East	Iquira	93				955-1078	0.05	CAM

54	Patía Valley	Patia-Guachicono	Central C.	West	Patía, La Vega, La Sierra, Rosas	9299	1186			612-1443	3.5	CRC
55		**Rocky massifs**	Isolated hills	Central & North	Patía, Timbío, Mercaderes							CRC
56		**Juanambu-Guaitara**	Deep canyons	South	Leyva, Policarpa, El Rosario, Taminango							CORPONARIÑO
57	Santander Region	Catatumbo	Eastern C.	East	Ocaña, Río de Oro, Ábrego	1583	13528	2231		481-1778	0.48	CORPONOR
58		Chicamocha	Eastern C.	West	Girón		448			1159-1364		CAS
59		Chucurí	Eastern C.	West	S. V. de Chucurí, Betulia, Zapatoca			23181		178-1776		CAS
60		De Oro	Eastern C.	West	Bucaramanga, Floridablanca, Pidecuesta	2638	8363	16		650-1798	4.82	CDMB
61		Direct to Magdalena	Eastern C.	West	Ocaña, río de Oro	617		41		1453-1553	0.17	CAS
62		Lebrija	Eastern C.	West	Ocaña, Charta, Tona, Lebrija	2537	22139	196		280-1776	0.54	CDMB
63		Oponcito	Eastern C.	East	S. V. de Chucurí			597		1011-1221		CAS
64		Pamplonita	Eastern C.	East	Cúcuta, Bochalema	186	15973			304-1756	0.15	CORPONOR
65		Sardinata	Eastern C.	East	Lourdes	147				1325-1429	0.09	CORPONOR
66		Simana	Eastern C.	West	Ocaña		24			1511-1563		CORPOCESAR
67		Sogamoso	Eastern C.	West	Girón	339	5172	30518		177-1785	0.17	CAS
68		Suarez	Eastern C.	West	Los Santos			1		678-678		CAS
69		Zulia	Eastern C.	East	Cúcuta, Gramalote, Santiago, San Cayetano, Cucutilla, Salazar, Durania	1187	10559	542		154-1696	0.37	CORPONOR

Abbreviations for the Jurisdictions of Environmental Authority. **COROPOCESAR**: Regional Autonomous Corporation of Cesar. **CORPAMAG**: Regional Autonomous Corporation of Magdalena; **CAR**: Regional Autonomous Corporation of Cundinamarca; **CORPOTOLIMA**: Regional Autonomous Corporation of Tolima; **CAM**: Regional Autonomous Corporation of Alto Magdalena; **CORANTIOQUIA:** Regional Autonomous Corporation of Central Antioquia; **CVC**: Regional Autonomous Corporation of Cauca Valley; **CRC**: Regional Autonomous Corporation of Cauca; **CAS**: Regional Autonomous Corporation of Santander; **CDMB**: Regional Autonomous Corporation for the Defence of the Bucaramanga Plateau; **CORPONOR**: Regional Autonomous Corporation of the Northeastern Border; **CARDIQUE**: Regional Autonomous Corporation of the Dique Canal; **CORPOCARIBE:** Regional Autonomous Corporation of the Caribbean.

Appendix 6. List of Tropical Dry Forest (TDF) orchid "core" recorded in five tropical dry forest regions in Colombia. Available only elctronically as supplemnetal material at: http://www.lankesteriana.org/LankesterianaJournal/17(1)/Reina_rodriguez%20et%20al%202017%20Appendix6.pdf