Biogeography of the Colombian oak, Q*uercus humboldtii* Bonpl: geographical distribution and their climatic adaptation

Carlos E. González
Doctoral Student, Department of Geography, King's College London/ Visiting Researcher, International Centre for Tropical Agriculture (CIAT)/Museo de Historia Natural, Universidad del Cauca, A. A 6713, Cali, Colombia. carlos.gonzalez_orozco@kcl.ac.uk, cegonzal@hotmail.com

Andy Jarvis
Senior Scientist, International Plant Genetic Resources Institute (IPGRI)/ International Centre for Tropical Agriculture (CIAT), A.A 6713, Cali, Colombia. a.jarvis@cgiar.org

Juan Diego Palacio
Senior Researcher, Instituto Alexander von Humboldt, (CIAT), A.A 6713Cali, Colombia.
jdpalacio@humboldt.org.co

ABSTRACT

Baseline information on the biogeography of the species *Quercus humboldtii* Bonpl is presented. This species, commonly known as Roble, has many uses for local communities, but has recently been placed in the IUCN category of "low risk/conservation depending". Prior to initiating conservation efforts, it is important to have baseline information on the species. This study analyses the geographic distribution of the species, and examines its climatic adaptation. A database of all known observations of *Q. humboldtii* in Colombia and Panama is presented, including a new registry of the species between the Western and Central cordilleras, in the Serranía de San Lucas at 1.200 meters above sea level. The database was used to examine the species distribution. This is done using both a qualitative assessment of the points of observation, and through predictive species distribution modeling. The species is found across all three cordilleras of the northern Andean region, from the department of Nariño in Colombia to the southern regions of Panama. *Q. humboldtii* has a wide climatic adaptation, from low to high elevations (representing a mean temperature from 9.3^{o}C to 27.9^{o}C), and wet to dry environments (788mm/year – 2681mm/year). The species could be split into two climatic clusters, with differing adaptations to mean temperature; low elevations and high elevations. The main municipalities where the species is likely to be found are listed. No climatically unique and geographically succinct clusters of *Q. humboldtii* populations are found, providing little evidence for splitting the species apart. Genetic and morphological studies are needed to reach concrete conclusions.

Key words: Biogeography, climate, Colombia, *Quercus humboldtii*, species distribution

RESUMEN

Información básica sobre la biogeografía de *Quercus humbildtii* Bonpl. es presentada. Esta especie tiene variados usos para la comunidad y es conocida como “Roble”. La Unión Internacional de la Conservación de la Naturaleza la incluye dentro de la categoría de Bajo Riesgo / Dependiendo de la Protección. Para la consolidación de buenos esfuerzos en su conservación es fundamental y prioritario tener nuevos elementos sobre el conocimiento de la especie y sus poblaciones. Este estudio analiza la distribución geográfica de las especies y examina su adaptación climática. Para el análisis y distribución de las especies se construyo una base de datos que incluye todas las observaciones conocidas o reportadas para *Quercus humboldtii* en Colombia y Panamá. Esto fue hecho usando una evaluación cualitativa de los puntos de observación y también una modelación predictiva de su distribución. La especie se reporto a lo largo de toda la región norte de la cordillera de los Andes, desde el departamento de Nariño en Colombia hasta la zona sur de Panamá, incluyendo nuevos reportes en otras formaciones geográficas aisladas como la Serranía de San Lucas a 1200 m. *Quercus humboldtii* tiene una amplia adaptación climática distribuyéndose desde bajas hasta altas elevaciones (representando un promedio de temperatura desde 9.3ºC hasta 27.9ºC, y cubriendo desde ambientes secos hasta húmedos (788mm/año- 2681mm/año). La especie podría ser dividida en dos agrupaciones climáticas, que difieren en sus adaptaciones de temperatura promedio, y a bajas o altas elevaciones. Los principales Departamentos y Municipios donde la especie podría ser encontrada fueron listados. No fueron encontradas agrupaciones climáticas únicas que sugieran la existencia de poblaciones cercanas de *Quercus humboldtii*, dando poca evidencia para dividirlas en varias especies. Son necesarios estudios genéticos y morfológicos para llegar a conclusiones concretas.

Palabras clave: Biogeografía, clima, Colombia, distribución de especies, *Quercus humboldtii*

INTRODUCTION

Quercus humboldtii Bonpl is a woody tree known in Colombia as “roble común”. It is from the family Fagacea and has a Laurasian origen (Hernandez et al. 1980). The Fagacea family is widely distributed across Colombia. The altitudinal range of *Q. humboldtii* is from 1000 to 3200 m. It is found on all three Andean cordilleras and some lowland inter-Andean regions. According to Cronquist taxonomical classification (1988), it is in the Fagales order, sub-genera *Erythrobalanus* (Spach.) Oersted. According to Manos et al. (1999) the genus *Quercus* has 500 species distributed in the northern hemisphere, with a mid latitude holartic origin while the closest genus, *Trigonobalanus* comes from the northern hemisphere of the new world (Palacio 2001). *Quercus* species have 2n=24 chromosomes (Alvarado & Coba 1989).

Q. humboldtii is found in fragments of Andean forests. The IUCN red plants book defines *Q humboldtii* as “lr-cd” (low risk/ conservation depending), but continuing deforestation in the northern Andes, and the subsequent fragmentation of populations is threatening the species gene pool. If populations further decrease, in five years time it may be at risk of becoming an endangered species (Calderon, 1999)

The species is widely known in Colombia, having many common names, including roble, roble Amarillo, roble Negro, and roble blanco (Pacheco & Pinzon, 1997). In studies by Lozano &

Torres (1974) seven Colombian *Quercus* types were cited, being found in Tolima, Cauca, Boyacá and Valle del Cauca departments. They have cited different "roble" names or synonyms of *Quercus humboldtii* as separate taxonomic species (for example, *Q tolimensis, Q almaguerensis, Q lindenii, Q colombiana, Q boyacensis*). However, Cavelier et al. (1994) classify all roble in Colombia as a unique species, *Quercus humboldtii* Bonpl.. Doubts remain as to the true taxonomy of the species.

Given the wide distribution across Colombia, conservation efforts must include measures to conserve the genetic diversity within the species, as well as populations. Cavelier et al. (1995) explored systematic RAPDS techniques in *Q humboldtii*. Fernandez (2001) has also been developing micro-satellite genetic techniques for Colombian Fagaceae species, information is available at the website: http://araneus.humboldt.org.co/inventarios/robles.htm.

Understanding the spatial distribution of a species is of most importance in assessing the conservation status and in suggesting possible conservation decisions that must be taken (Guarino et al., 2001). Knowledge of the species distribution provides baseline information on the areas where effort can be focused. Conservation biologists are presented with two main methods for assessing species distribution. Point observations can be used to examine the distribution of a species, but this method tends to underestimate the true distribution if the observations are an incomplete representation of geographic range of the species (Anderson et al, 2002). Predictive species distribution modeling in some part solves this problem, and has received particular focus in ecology in recent years (Guisan and Zimmerman, 2000). Typically these methods use point observations of a species to understand the biophysical adaptation of the species in question, and then extrapolate the potential distribution to larger regions. Numerous statistical models have been developed, including genetic algorithm (Anderson et al, 2002), logistic regression (Draper et al, 2003), and principal components analysis (Jarvis et al, 2003; Robertson et al. 2001) amongst others. The biophysical variables that may drive species distribution include climate, habitat, soil and topographic derivatives (Guarino et al., 2002).

This study is aimed to make a broad assessment of the biogeography of *Quercus humboldtii* in Colombia. Specifically, the goals of this study are (1) to identify the climatic adaptation of *Q humboltii* (2) to identify possible adaptive clusters that indicate within-species variation, and (3) to map the potential distribution of the species. It is hoped that this assessment may shed some light as to the true taxonomy of the species, and provide baseline information from which to drive conservation efforts.

METHOD

Data collection

A total of 132 geo-referenced accessions and herbarium specimens of *Q humboldtii* were compiled for this study. The data was created from online databases of international herbariums (e.g. New York and Missouri Botanical Garden), from visits to national herbariums and some limited fieldwork. Geographic coordinates were assigned using online gazetteers (www.astrored.org; www.nima.mil; www.index.jsp; www.calle.com) and paper maps. In the context of this paper we are accepting *Q. humboldtii* as a single species.

Data analysis

In order to predict the geographic distribution of *Q. humboldtii*, and analyze its climatic adaptation a computer GIS tool named FloraMap (Jones & Gladkov, 1999) was used to develop predictions of potential distribution based on climatic factors. The model uses point observations of a species to understand the climatic adaptation of a species, and then extrapolates to produce a continuous surface of potential distribution. This information can be combined with ancillary information (social, biological, genetic etc.) to further understand the species.

FloraMap assumes that the climates at points of observation and/or collection are representative of the complete environmental range of the organism. FloraMap uses 36 climate surfaces of rainfall, mean temperature and diurnal temperature range monthly values. The climate at the points of observation is used as a calibration set to compute a climate probability model. Each variable is extracted on each collection/observation of the organism, and subjected to a principal components analysis (PCA), which is then coupled with a probability model to map the potential distribution in areas between existing observations. The user is able to study the scores and loadings of the PCA in order to assess the climatic adaptation of the organism. FloraMap also offers a clustering algorithm (using Ward's method) to examine possible separations in climatic adaptations within the species. This function identifies individual observations/collections in each cluster, and also maps the predicted distribution of that climatic cluster. Jarvis et al. (2002) explains in detail the method that FloraMap uses to predict species distribution. Theoretical background can be found in Jones (1991), Jones et al. (1997) and the FloraMap manual in Jones & Gladkov (1999), which is available online at http://www.floramap-ciat.org.

The climate surfaces used in this study were produced by interpolating data from 2167 climatic stations distributed around Colombia, Ecuador and southern Panama. The grid cell size of each surface is 1 minute (approximately 2km at the equator).

The distribution of *Q humboldtii* was predicted using five principal components, which accounted for 95 % of variance in the dataset. Cluster analysis using Ward's method was applied, in order to identify different climatic adaptations within the species. The results of the cluster analysis were then combined to produce the optimal prediction of species distribution. The PCA scores and loadings were extracted, and analyzed in order to ascertain the climatic factors most important in shaping the distribution of *Q. humboldtii*. ArcGis software was used to visualize the results.

RESULTS

Distribution

Figure 1 shows the distribution of known observations of *Quercus humboldtii* (Fagaceae). As can be seen, it is found across most of the Andean region of Colombia.

Figure 1. Collection mapped for *Quercus humboldtii* in Colombia and Panama

The high resolution (2x2 Km) predicted map (Figure 2a) reveals the potential distribution and its climatic adaptation. In general terms, the climatic adaptation of the species has an average rainfall of 1753 mm/year, with a maximum of 2.681 mm/year and a minimum of 788 mm/year, a monthly mean temperature of 17.1 °C (ranging from 9.3^{o}C to 27.9^{o}C) and a diurnal temperature range of 10.6 °C (ranging from 6.8^{o}C to 13.7^{o}C).

The first principal component (which accounts for 54% of the variance) shows a negative correlation with all the monthly diurnal temperature range values, and a positive correlation with rainfall values. The second component (25 %) reflects a slight negative correlation with rainfall for the three dry months (July-Sept). In general, *Q humboldtii* appears to be most limited in distribution by rainfall, being best adapted to areas of high rainfall all year round.

Figure 2. Distribution and potential climatic adaptation for *Q humboldtii* in Colombia

Climatic clustering

The Principal Component Analyses (PCA) and cluster analysis of climate data revealed two clear climatic clusters within *Q humboldtii* (Figure 3). In general terms, the two clusters are separated altitudinally into high elevation populations (cluster 2), and lower elevation populations (cluster 1), most markedly defined by mean temperature differences. There is little seasonality where *Q humboldtii* is found, though the lower elevation cluster contains greater seasonality than the other (Figure 4). Climatic cluster 1 is distributed continuously along the mid-elevation flanks of the Andes, in all three cordilleras, whilst cluster 2 has a more fragmented and localized distribution around altitudinal maximal.

Figure 3. The two major different climatic clusters: low (1) and high (2) elevation.

Cluster 1

The first cluster includes 60 observation points. The range of this cluster stretches from the south to the north of Colombia mainly in corridors along the Cauca and Magdalena catchments. The western side of the eastern cordillera has the greatest potential coverage, with more scattered regions on the eastern side of the western cordillera and the western front of the central cordillera. The southern region contains less suitable environments than the northern part of the country. The average altitude value was 1574.8m. The annual average rainfall is 1892 mm/year, with a maximum of 2692 mm and a minimum of 1228 mm. The climatic pattern is characterized by rainfall concentrated during four months (Dec-March) but with a drier season from June-Sept. The average annual temperature is 22.5 °C (Figure 4: cluster 1).

Cluster 2

The second cluster has 71 points showing a bimodal rainfall pattern with peaks in April-May and October-November (Figure 4:cluster 2). The type of geographical distribution is localized on the edge of the eastern, western and central cordilleras. Climate patterns are dominated by: a rainfall range influence with peaks in October-January and May-June, a monthly mean rainfall of 1958 mm/year, a maximum of 2866 mm/year and a minimum of 951 mm/year with a standard deviation of 74.3 mm/year, the average altitude range was 2237m, a diurnal temperature mean of 17.0^{o}C, the diurnal mean monthly range value is 11.7°C. The first principal component (54% variance) has a positive correlation with rainfall values for all months except August and September. The second component has a negative correlation with diurnal temperature for all months and a negative correlation with rainfall in May-June and November and December. The temperature is positively related to all months, indicating that for this cluster temperature may be a more limiting factor. The southern region of the distribution generally has wetter environments in comparison with the dryer north.

Figure 4. Polar climate diagrams of *Q humboldtii* species. **(Cluster 1)** Represents the lower elevation cluster **(Cluster 2)** represents the high mountain cluster. Inner, middle and outer circles represent minimum, mean and maximum monthly temperatures respectively and sectors show monthly rainfall.

Both clusters include four biogeographically key regions. The major high probability areas in Colombia are: (a) Antioquia (central and southwestern part), area (b) Cauca (Central inter-Andean plateau and southeastern part) and Huila (southern part) (c) Santander, Norte de Santander and Boyacá departments and (d) across a west-east central belt around the coffee region.

Though environment alone cannot be used to distinguish potential taxonomic separations within a species, it has been shown to correlate well with intra-specific genetic differences (Segura et al., 2003). Combined with morphological analyses this information could shed light onto the ongoing taxonomical debate on *Q. humboldtii*. The two climatic clusters differ in geographic pattern only in terms of the altitudinal gradient (representing the gradient in mean temperature), and no regional associations. This indicates that the species is not found in disjunction geographic regions with vastly different environments, albeit existing in a broad environmental gradient from high to low temperatures. The high altitude populations are unconnected and cover small geographic areas, and so it is unlikely that these are biologically isolated from the lower altitude populations. Given the large environmental gradient that the species inhabits, it is expected to be genetically diverse in adaptive traits, or exhibit high levels of plasticity.

DISCUSSION AND CONCLUSIONS

This approach has produced more questions than answers. However, the results of this study show that *Q. humboldtii* has a wide climatic adaptation, from low to high elevations (representing a mean temperature from 9.3^{o}C to 27.1^{o}C), and wet to dry environments (788mm/year – 2681mm/year). However, no evidence was found that there are populations in specific geographic regions with different environments. The only climatic clustering that was found to exist separates high elevation populations from their lower elevation counterparts. This is not a separation of vastly different climates, but more a separation along a long and continuous environmental gradient. Segura et al. (2003) used a similar analysis to that made here to show

how the geographic clustering of climatic adaptations reflected strong genetic differences identified with conventional genetic analyses. However no such geographic separation was found here, suggesting that the species *Q. humboldtii* is indeed a single species. Genetic studies and conventional taxonomic evaluations of morphology are required to make concrete conclusions.

Though no observations have been registered of *Q. humboldtii* in Ecuador, there are corridors from Colombia where the climate is suitable for the species. In terms of data points, this example might be considered representative on the basis that predicted climate variables match with the current distribution.

There are a number of aspects, which a research agenda is looking towards depending mainly on financial support availability. The topics to be addressed are: dataset improvements, spatial analysis based on richness maps, genetic diversity maps, prioritizing *ex situ* conservation areas within Colombia, to locate the suitable distribution habitats, conducting *ex situ* molecular analysis and understanding *in situ* aspects based on climatologically variables that makes impact on *Q. humboldtii* conservation and preservation.

RECOMMENDATIONS

Conservation implications

The probability maps generated in this work closely match the general patterns in the natural distribution as described by Lozano & Torres (1974). However, the results presented here offer more detail, at a scale relevant for targeting conservation efforts. The species has been reported in 13 of the 33 Colombian departments, but these results suggest that other regions potentially harbor the species. It is believe that this method provides useful information for planning and *ex situ* conservation. A similar methodological case study conducted by Jarvis et al (2005), implemented successfully a predicting model for prioritizing areas within Paraguay for acquisition of germplasm of a crop gene pool for *ex-situ* conservation.

A list of municipalities presented below, separated by geographic region and departments, where the climate is suitable for *Q. humboldtii*, and where, given the forested habitats, the species is likely to be found. Cauca, Antioquia and Boyacá have the greatest number of municipalities potentially containing the species, but are also some of the municipalities under the greatest population pressure, and subsequently have a high threat of habitat loss.

Colombian municipalities at regional scale where *Q. humboldtii* may be found, and where conservation efforts could be focused is listed below. The list include the municipalities with the most favorable climatic conditions for *Q. humboldtii* in Colombia according to the FloraMap analysis:

1) Low-elevation climates (warmer temperatures): Nariño (south east of Ipiales, east of Funes, Puerres and Pasto, Santa Cruz, Samaniego, Los Andes, Cumbitara, east of Magui); Putumayo (nort west of Orito and Villa Garzon); Cauca (south of Santa Rosa); Huila (Pitalito, Isnos, south of San Agustin, center of Iquira and Teruel, north of Gigante); Caqueta (west of El Florencia, Puerto Rico, El Doncello); Meta (south central of La Uribe); Tolima (Alpujarra , Dolores, south

of Roncesvalles, east of San Antonio and north of Chaparral, Venadillo, Alvarado, Libano); Valle del Cauca (central east of Ginebra, Guacari, west of Sevilla); Valle del Cauca (eastern part of Dagua and Buenaventura); Quindio (La Tebaida); Cundinamarca (Pacho, Vergara, El Peñon); Risaralda (Quinchia, Apia, Guatipa); Caldas (Aguadas, Ancerma); Antioquia (Jerico, Tamesis, Santa Barbara, west of Buritica, center of Ituango, Betulia, east of Turbo); Cordoba (east of Tierralta); Bolivar (Morales), Norte de Santander (west of El Carmen, Toledo); Santander (El Playon, Bucaramanga, Lebrija); Casanare (Sacama and north west of Tacama); Boyaca (Socota, Labrabzagrande, Mongua); Magdalena (east of Santa Marta).

2) High elevation climates (lower temperatures): Huila (east of Algeciras); Nariño (south of El Tablon); Putumayo (north of Colon); Cauca (north of Balboa and Argelia,east of La Sierra, central of Timbio, central eastern of Jambalo, Toribio and Corinto, north western and east of Paez, west of Suarez); Valle del Cauca (east of Praderas); Tolima (central of Planadas and Villa Rica); Antioquia (Andes, Cañasgordas, Liborina, Sabanalarga, San Vicente); Boyaca (Tinjaca, Moniquira, San Jose de Pare, north of Chiscas); Santander (north east of Puente Nacional, central east of Carcasi, north of Piedecuesta); Norte de Santander (center of Cucutilla and Arboledas, south of Abrego, north of Villa Caro); Cordoba (east of Tierralta), Arauca (north of Tame); Cesar (across the Perija range on the eastern of Chiriguana, la Jagua de Iribico, Becerril, La Paz, Agustin Codazzi and north west of Valledupar), Guajira (east of Urumita); Magdalena (north east of Aracataca and central part of Cienaga).

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