

OAK FORESTS TYPES OF *Quercus humboldtii* IN THE Guantiva-La Rusia-Iguaque CORRIDOR (SANTANDER-BOYACÁ, COLOMBIA): THEIR CONSERVATION AND SUSTAINABLE USE

Tipos de bosques de roble (*Quercus humboldtii*) en el corredor Guantiva-La Rusia-Iguaque (Santander-Boyacá, Colombia): su conservación y uso sostenible

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Palabras clave: bosques de robles, manejo bosques tropicales, robles, conservación, uso sostenible

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ABSTRACT

Characterizations of oak forests according to their floristic composition and structure and the identification of the main use requirements of local communities were performed. This permitted recommendations for the sustainable use and preservation of these forest types in the Guantiva-La Rusia-Iguaque conservation corridor (Santander-Boyacá, Colombia). The oak forests correspond to the *Quercus humboldtii* - *Billia rosea* major forest formation, which can be categorized into a hierarchical structure of seven forest types. The *Q. humboldtii* - *Ocotea calophylla* forests present in the high Andean fringe (>2200-3200 m.a.s.l); the *Q. humboldtii* - *Alchornea grandiflora* forests, common in the Andean region include two types of forests, *Q. humboldtii* - *Blakea cuatrecasii*, and *Q. humboldtii* - *Cyathea multiflora* forests; furthermore, these types of forests comprise the *Q. humboldtii* - *Daphnopsis caracasana* and *Q. humboldtii* - *Pouteria baehniiana* forests. The final forest type is the *Virola macrocarpa* - *Q. humboldtii* forests present in the sub-Andean life zone. According to interviews with members of local communities oak forests are considered the main components

of ecosystems of high cultural and social value. The interviews identified two principle uses of oaks, for fuel and for land tenure and property maintenance (fence posts, stakes for crops, timber and tool handles). According to ecological characterization and conservation status assessments the *Virola macrocarpa* - *Q. humboldtii*, *Q. humboldtii* - *Pouteria baehniiana* and *Q. humboldtii* - *Daphnopsis caracasana* forests can be used by the community with technical prescriptions. The *Q. humboldtii* - *Blakea cuatrecasii* and *Q. humboldtii* - *Ocotea calophylla* forests should not be used under any circumstance and should be subject to strict strategies for their protection and ecological restoration. The future of oak forests is uncertain unless appropriate strategies based on the generation of co-management agreements with local communities for sustainable use and conservation are proposed and implemented.

RESUMEN

Los bosques de robles en el corredor Guantiva-La Rusia-Iguaque corresponden a la formación mayor de *Quercus humboldtii* y *Billia rosea*, los

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cuales se clasificaron en una estructura jerárquica de siete tipos: Bosques de *Q. humboldtii* y *Ocotea calophylla* (franja altoandina >3200 m), la gran formación de *Q. humboldtii* y *Alchornea grandiflora*, en la región andina con el robledal de *Q. humboldtii* - *Blakea cuatrecasii* y el de *Q. humboldtii* - *Cyathea multiflora*. En la parte baja de la región andina se diferenciaron los bosques de *Q. humboldtii* y *Daphnopsis caracasana* y los de *Q. humboldtii* y *Pouteria baehniiana*. Los bosques de *Virola macrocarpa* y *Q. humboldtii* están presentes en la zona de vida sub-andina. Los robledales son considerados ecosistemas de alto valor cultural y social con dos prácticas principales de uso: como fuente de combustible y en el mantenimiento de las fincas (postes, estacas, madera). Según la caracterización florística y estructural, los bosques de *Virola macrocarpa* - *Q. humboldtii*, los de *Q. humboldtii* - *Pouteria baehniiana* y los de *Q. humboldtii* - *Daphnopsis caracasana* podrían ser utilizados por la comunidad, bajo prescripciones técnicas. Los bosques de *Q. humboldtii* - *Blakea cuatrecasii* y de *Q. humboldtii* - *Ocotea calophylla* no se deben usar, bajo ninguna condición, y deben ser objeto de un programa de protección estricta y restauración ecológica. Se deben implementar estrategias de conservación basadas en la generación de acuerdos de comanejo entre las comunidades locales y las instituciones ambientales que faciliten su conservación bajo esquemas de uso sostenible.

INTRODUCTION

The presence of oak forests (*Quercus humboldtii*) in Colombia illustrates the southern boundary of the geographic distribution of this important Holarctic lineage. Its appearance in Colombia is very recent (300 000 years BP) and its ecological dominance is very marked in the three branches of the Andes and isolated massifs in the Caribbean region of the country, between 700 and 3500 m. (Cuatrecasas, 1958; Lozano & Torres, 1974; Rangel & Lozano, 1986; Rangel *et al.*, 2005, 2008, 2009; Van der Hammen, 2008; Rangel & Avella, 2011). In the Andean region of Colombia, currently less than 10 % of the original forests extent and probably less than 5% of the high Andean forests remain con-

served (Gentry, 1993). However, a more cautious floristic characterization suggests that oak forests have been reduced by 60% (Rangel 2000; 2005).

Colombian forest legislation in the last century was based on concessions and permissions where the nation supported the exploitation of the forests to the benefit of a few. This degrading situation and the almost extinction of various populations of hardwood tree species motivated the promulgation of a series of prohibitions on forest harvesting by the Instituto Nacional de Recursos Naturales Renovables -INDERENA-, including Resolution 0316 in 1974, by which was prohibited for an indefinite period of time all types of use or harvesting of oak (*Quercus humboldtii*) in natural stands in the entire country. Subsequently, the oak harvest prohibition was removed in other regions of the country as the Departments of Antioquia, Cauca and Nariño where harvesting was allowed, except for the production of firewood, charcoal or pulp. In the last decade, the Ministry of the Environment, Housing and Territorial Development re-established, through Resolution 0096 in 2006, the indefinite prohibition of oak harvesting throughout the country.

However, in the resolution the sustainable use of the specie is considered as an essential mechanism for its conservation. As a result, local environmental authorities were authorized to carry out technical studies evaluating options for the sustainable use of the species taking into account its wide distribution, the environmental services it provides and its potential for restoration and sustainable use.

Andean oak forests, in addition to their high floristic richness, offer important ecosystem services. The wide distribution of oak in the Colombian Andean region makes it one of the most important species in biological and socio-economic contexts because of its use in restoration programs, management and sustainable use of goods, and in the provision of environmental services (MAVDT, 2006). Subsequent to Resolution 096, several alternative land uses were proposed, including the declaration of protected areas, improvement of forest exploitation processes by local communities, and large projects involving forest harvest.

Oak forest fragments of considerable extent can be found within the Guantiva-La Rusia-Iguaque "GRI" conservation corridor, located in Santander and Boyacá departments (Solano *et al.*, 2005). Based on the characterization of the floristic composition, aspects of the structure and conservation status, the present study proposes a classification of the oak forests types in the GRI conservation corridor. This oak forest classification along with information related to traditional knowledge and use practices of local communities can be the basis for defining a program of sustainable forest management. We estimate that proposed strategies to conserve oak forests, should take into account not only scientific knowledge but also traditional knowledge, interests and basic needs of local communities.

MATERIAL AND METHODS

STUDY AREA

The Guantiva-La Rusia-Iguaque conservation corridor is located on the western slope of the eastern cordillera in the departments of Boyacá and Santander. This corridor is one of the largest areas of well-conserved oak forest remaining in Colombia with an area of approximately 171 293 ha (Solano *et al.*, 2005). It influences the hydrological dynamics of the Suarez and Chicamocha river basins that supply potable water to most of the population of Santander and Boyacá, as including cities such as Duitama, San Gil, and Charalá. The present study was carried out in the central area of the conservation corridor encompassing 157 000 ha, where approximately 57 000 ha of oak forests persist.

The human population of the municipal areas of this study is 192 773 inhabitants. Sixty-four percent of the population is located in urban areas and 36% lives in rural areas (DANE, 2005). Habitat fragmentation is extensive, caused by land tenure dominated by "minifundios" - small landholders (properties of 1-5 ha) and "microfundios" (properties of < 1ha). Generally, most of the forested lands are on private property in which land owners are cattle farmers, most of whom have abandoned steeper areas (Solano *et al.*, 2005). The main economic activities in

the rural areas are agriculture and livestock. The agricultural sector is characterized by traditional exploitation mainly in slope areas, intensive labor, low crop rotation and dependent on the rainy season (Solano *et al.* 2005). Nowadays, the land cover in this area includes 36% natural forest (57 000 ha), 22% mosaics of grassland and agriculture (34 200 ha), and 18% grassland (28 500 ha) (Melo, 2008). Along the topographic gradient (1800-3200 m.), there are semi arid, sub humid, and hyper humid climate types. The forests are generally established in rugged terrain with slopes greater than 50%.

An historical analysis of the exploitation processes of the oak forests present in the Guantiva-La Rusia-Iguaque region, include since the pre-Columbian inhabitants, two indigenous groups, the Chibchas, who were settled in the area now corresponding to the highlands of the Boyacá department, and the Guane group, which was found in some areas of the present Santander department. The region was characterized as an intermediate zone for commercial and cultural exchange between the Guanes and the Chibchas (Raymond, 1997; Solano, 2006). The Chorographic commission (Ancizar, 1853), on its journey to the Charalá region, classified the area as dominated by producers of cotton, corn, turmas potatoes, cassava, plantains, fruits, and panela. In addition, particularly important in this case, they noted the presence of valuable wood species, especially "cedars" (*Cedrela* spp.).

Extensive animal husbandry has had an important role in the region. The slim livestock from the eastern Llanos used to be fattened and then sold to other towns in Santander (Solano, 2006). The decrease in agricultural land use might have been a consequence of the large proportion of areas corresponding to subparamo and rugged terrain that do not offer suitable opportunities for agricultural development, and favor the region's isolation (Raymond, 1997). The removal of the oak forests, in the early 20th century, was mainly caused by the occupation of highlands as a result of human migration provoked by political unrest and violence, high rates of poverty, agricultural expansion, re-suitability of properties by the landowners, family heritage dynamics and the construction of roads (Bello, 2006).

Oak was not considered a valuable species by the local communities in the early 20th century, its demand as a source of wood began during the first half of the century by construction-storage companies in need of levers for the coal mines in Paz del Rio and ties for the national railroad tracks Bello (2006), Solano (2006) and Avella & Cárdenas (2010) argue that the main uses of the oak forests that shaped their current status were the following: the development of extensive animal husbandry; overexploitation of valuable wood species such as cedar (*Cedrela montana*), punte o comino (*Aniba perutilis*) and Colombian pine (*Podocarpus oleifolius*), mainly commercialized in Tunja, Duitama and Bogota. The oak was required for the fabrication of poles and levers for mining activities as well as the fabrication of charcoal mainly in Paipa, Raquira, and Arcabuco. In addition, there was a strong demand for oak wood for the construction of the railroad tracks by the Colombian Railroad System. It is estimated that for the construction of the rail track from Zipaquirá to Chiquinquirá (105 km), 9252 tons of charcoal, 665 tons of firewood, 12232 tons of lumber, 3419 tons of round wood and 464 tons of other timber products were used. To cover these needs it was necessary to cut down at least 100 000 trees of the most valuable wood present in the region's (Franco, 2007).

METHODOLOGY

The research comprised two phases: i) the definition of the different types of oak forests, ii) and the opinions of local communities on these forests and their uses of them. The classification of oak forests was made based on a combination of the floristic approach of the classic sigmatist school (Braun-Blanquet, 1979), which is followed by botanists and biologists and the structural approach followed by foresters (Cantillo & Rangel, 2011), which gives more weight to inventories of higher-strata species (trees). We include information from 54 plots with 1000 m² each one, which were located along an elevation gradient from 1800 to 3200 m.; those individuals with a DBH \geq 10cm were counted. We followed the method described by Rangel & Lozano (1986) to differentiate strata, which considers the following

height intervals of individuals: (r): ground (<0.3 m); (h): herbaceous (0.3-1.49 m); (ar): shrubby (1.5-4.9 m); (A): treelets (5-11.9 m); (Ai): inferior arboreal (12-25 m) and (As): superior arboreal (>25 m). In each stratum the number of individuals was counted. These values were used to estimate the relative abundance of each species. Vegetation cover was estimated as a percentage in relation to the surface area or plot. For each individual we calculated the projected area of the canopy over the ground in square meters. The clearances for lack of foliage or branches were not taking in account (Cleef, 1981; Cleef *et al.*, 1984). Estimating species coverage by stratum facilitates estimating the coverage of each species in the forest complex, and also serves to know details of the dynamics of the vegetation with its various states as juveniles, understory individuals and canopy individuals (Cleef *et al.*, 1984; Rangel, 1994). Detailed applications of the procedure in the field are explained in ECOANDES project contributions (Cleef *et al.*, 1984; Rangel *et al.*, 2003; Rangel *et al.*, 2005). The basal area (BA) for each individual was calculated with the DBH value as follows: $BA = (\pi/4) \times (DBH^2)$. The IPF (Physiognomic Predominance Index) was also calculated (coverage (%) + density (%) + dominance (%)) (Rangel & Garzón, 1994) as well as the relative IVI (Importance Value Index or Cottam Index, Finol, 1976), which is relative density (%) + relative dominance (%) + relative frequency (%) for the species present in the superior arboreal (As), inferior arboreal (Ai) and treelets (Ar) strata. We used TWINSpan (McCune & Mefford, 1997) to detect separation tendencies and define the floristic composition of different forests.

The nomenclature of the different oak forests is based on the dominant species (high values of percent cover, basal area, and relative IVI index). The tables with the floristic composition of the different oak forest include the value of basal area. Voucher specimens under collection number of AAM (Andrés Avella M.), RML (Ruth Medina Lozano) y SPA (Sonia Patricia Angel) were deposited in the Herbario of Distrital University (UDBC). The complete phytosociological treatment will be presented elsewhere. Also, we conducted interviews about the knowledge, conservation, and exploitation practices with some members of local com-

munities recognized as an expert following the recommendations proposed by Díaz (2008) and Jimenez *et al.* (2011) about make the interviews with spontaneous questions that emerging in the course of the conversation, facilitating communication and understanding of the topics.

RESULTS

OAK FOREST TYPES IN THE GUANTIVA-LA RUSIA-IGUAQUE CONSERVATION CORRIDOR

The oak forests in the area of interest correspond to the *Q. humboldtii* and *Billia rosea* forest formation, which can be categorized into a hierarchical structure of seven types of forests as shown in figure I.

Major formation dominated by *Q. humboldtii* and *Billia rosea*

Tables I and II

Floristic composition and structure. Dominant species are: *Quercus humboldtii*, *Billia rosea*, *Compsoneura rigidifolia* and *Clethra fagifolia*. The forests

have an average canopy height of 17 m. The superior arboreal stratum (As) is represented by *Q. humboldtii* (5% of coverage), *Virola macrocarpa* (1%), *Aniba perutilis* (1%), and *Sterigmapetalum tachirensis* (1%). In the inferior arboreal stratum (Ai), *Quercus humboldtii* dominates with 22%, followed by *Virola macrocarpa* (5%), *Billia rosea* (5%), *Compsoneura rigidifolia* (1%), and *Clusia cf. bracteosa* (1%). In the treelets' stratum (Ar), *Quercus humboldtii* was predominant with 8%, followed by *Clusia schomburgkiana* (3%), *Ladenbergia macrocarpa* (2%), and *Clusia cf. bracteosa* (2%). The dominants of the shrubby stratum were *Cyathea cf. multiflora* with 2%, followed by *Q. humboldtii* (2%), *Palicourea sp.* (EHC 366) (1%), *Ladenbergia macrocarpa* (1%), and *Clusia discolor* (1%). The species with a greater relative IVI (%) and IPF (%) were *Q. humboldtii* (23-32%), *C. rigidifolia* (3-5%), *V. macrocarpa* (3-5%), *Clusia schomburgkiana* (2-3%), *Clusia cf. bracteosa* (2-3%), and *Hyeronima huilensis* (2-2%). A total of 75 individuals (shrubby to arboreal strata), 62 species and 3.7 square meters of basal area (BA) were found by plot of 1000 square meters surface.

Geographic distribution: The vegetation of this major formation includes oaks from the sub Andean and Andean region between 1820 and 3250 m.

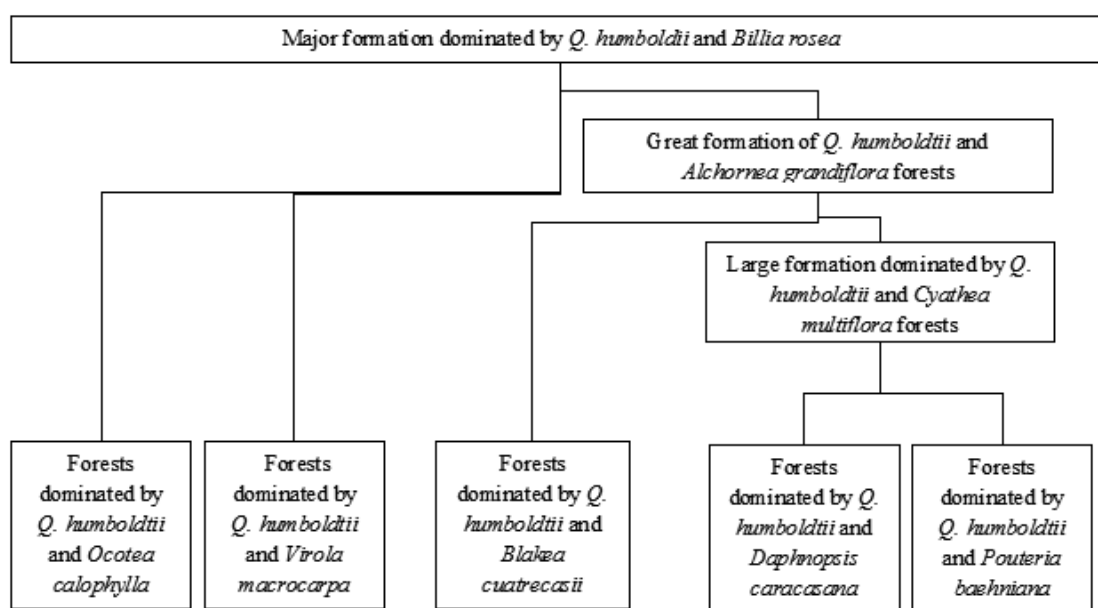


Figure I. Hierarchical structure of different types of oak forests in the Guantiva-La Rusia-Iguaque conservation corridor

The landscapes include steep ridges, abrupt crests, and moderately steep ridges with slopes between 50 and 75%. There are also flat areas with slopes less than 25%. The parent material derived from clastic sedimentary rocks with interbedded sandy-clay-loam structure. The soils are moderately deep.

Conservation status: Human intervention from low to moderate degree because the landscape includes steep ridges, steep ridges and moderately steep ridges. The patches of oak forest growing on flat areas show a high degree of human intervention, which means low degree of conservation.

Forests dominated by *Q. humboldtii* and *Ocotea calophylla*

Table I

Floristic composition and structure: Dominant species are: *Q. humboldtii*, *Clusia multiflora*, *Weinmannia tomentosa*, and *Ocotea calophylla*. The inferior arboreal stratum (Ai) is represented by *Quercus humboldtii* with 69%, followed by *O. calophylla* (3%), *Centronia brachycera* (3%), and *Miconia* sp. (AAM 983) (3%). In the treelets' stratum (Ar), *Q. humboldtii* was predominant with 21%, followed by *C. multiflora* (3%), *W. tomentosa* (3%), *Schefflera velutina* (2%) and *Oreopanax bogotensis* (2%). The dominants of the shrubby stratum were *Q. humboldtii* with 2%, followed by *Cyathea* cf. *multiflora* (1%), and *Miconia ligustrina* (1%). The species with a greater relative IVI (%) and IPF (%) were *Q. humboldtii* (48-70%), *O. calophylla* (4-4%), *C. multiflora* (3-3%) and *W. tomentosa* (3-4%). A total of 83 individuals (shrubby to arboreal strata), 12 species and 4.6 square meters of basal area (BA) were found by plot of 1 000 square meters surface.

Geographic distribution: These oak forests grow on the Andean region between 2316 and 3250 m., especially in the high Andean fringe. The landscapes include steep ridges, abrupt crests, and moderately steep ridges with slopes between 50 and 75%.

Conservation status: Due to its localization in the top of mountains (high Andean fringe), these patches of

oak forest shows a low degree of human intervention which means a good status of conservation.

Forests dominated by *Q. humboldtii* and *Virola macrocarpa*

Table I

Floristic composition and structure: Dominant species are: *Q. humboldtii*, *Billia rosea*, *Vismia* cf. *baccifera*, *Elaeagia mariae*, *S. tachirensis* and *V. macrocarpa*. The superior arboreal stratum (As) with low coverage is represented by *Q. humboldtii* (2%), *V. macrocarpa* (1%), *Aniba perutilis* (1%) and *S. tachirensis* (1%). In the inferior arboreal stratum (Ai), *V. macrocarpa* dominates with 9%, followed by *Q. humboldtii* (6%), *Compsonera rigidifolia* (4%), *Eschweilera sessilis* (2%), *B. rosea* (2%), *Faramea flavicans* (2%) and *S. tachirensis* (2%). In the treelets' stratum (Ar), *C. rigidifolia* dominates with 5%, *V. macrocarpa* (2%), *Clusia schomburgkiana* (2%), *F. flavicans* (2%), and *S. tachirensis* (1%). The dominants of the shrubby stratum were *Micropholis crotonoides* with 3%, followed by *Alchornea grandiflora* (2%), and *Myrsine pellucida* (1%). The species with a greater relative IVI (%) and IPF (%) were *Q. humboldtii* (6-8%), *V. macrocarpa* (11-14%), *C. rigidifolia* (11-9%), *S. tachirensis* (3-4%), *F. flavicans* (4-4%), and *B. rosea* (3-3%). A total of 94 individuals (shrubby to arboreal strata), 33 species and 3.2 square meters of basal area (BA) were found by plot of 1000 square meters surface.

Geographic distribution: These oak forests grow on sub Andean region between 1850 and 1950 m. The landscapes include steep ridges and abrupt crests with slopes between 12 and 50%.

Conservation status: These oak forests shows a low degree of human intervention which means a good status of conservation due to the fact that they are inside a Protected Area called Estación Biológica Cachalú. However, in the regional landscape, these oak forests had been the most affected by the coffee plantations. There are only reduced tracts of these forests in good conservation status.

Great formation of *Q. humboldtii* and *Alchornea grandiflora* forests

Table II

Floristic composition and structure: Dominant species are: *Q. humboldtii*, *Ilex laurina*, *Hyeronima huilensis*, *Clusia* cf. *bracteosa*, and *Alchornea grandiflora*. The superior arboreal stratum (As) with low coverage is represented by *Q. humboldtii* (3%), *H. huilensis* (2%), and *Clusia* cf. *bracteosa* (1%). In the inferior arboreal stratum (Ai), *Q. humboldtii* dominates with 16%, followed by *Clusia* cf. *bracteosa* (4%), *Billia rosea* (2%), *A. grandiflora* (2%), and *Clusia schomburgkiana* (2%). In the treelets' stratum (Ar), *Q. humboldtii* dominates with 8%, *C. schomburgkiana* (4%), *Clusia* cf. *bracteosa* (3%), and *Ladenbergia macrocarpa* (3%). The dominants of the shrubby stratum were *Cyathea* cf. *multiflora* with 3%, followed by *Q. humboldtii* (2%), *Eugenia* sp. (SPA 39) (2%), and *Ladenbergia macrocarpa* (2%). The species with a greater relative IVI (%) and IPF (%) were *Q. humboldtii* (20-27%), *Clusia* cf. *bracteosa* (4-5%), *H. huilensis* (4-4%), *C. schomburgkiana* (4-4%), *L. macrocarpa* (4-4%), and *A. grandiflora* (4-4%). A total of 68 individuals (shrubby to arboreal strata), 17 species and 3.2 square meters of basal area (BA) were found by plot of 1000 square meters surface.

Geographic distribution: These oak forests grow on the sub Andean and Andean region between 1 820 and 2600 m. The landscapes include steep ridges, and moderately steep ridges with slopes between 50 and 75%. The soils are moderately deep.

Conservation status: These oak forests types show medium to high degree of human intervention which means an intermediate status of conservation. Generally speaking, this region is where the local communities use in a more intensive way the oak forests. The degradation of arboreal and treelets strata is high and in the regional landscape, the patches of this type of forests are fragmented and scarcely connected, therefore only a few of these forests are in good conservation status.

Forests dominated by *Q. humboldtii* and *Blakea cuatrecasii*

Table II

Floristic composition and structure: Dominant species are: *Q. humboldtii*, *Blakea cuatrecasii*, and *Clusia inesiana*. The inferior arboreal stratum (Ai) is represented by *Q. humboldtii* dominates with 7%, followed by *Clusia* cf. *bracteosa* (1%), *C. inesiana* (1%) and *Hyeronima huilensis* (1%). In the treelets' stratum (Ar), *Q. humboldtii* dominates with 13%, *B. cuatrecasii* (3%), *C. inesiana* (2%), and *Eugenia* sp. (SPA 39) (2%). The dominants of the shrubby stratum were *Blakea quadrangularis* with 3%, followed by *Q. humboldtii* (2%), and *Alchornea grandiflora* (1%). The species with a greater relative IVI (%) and IPF (%) were *Q. humboldtii* (42-59%), *B. cuatrecasii* (9-8%), *Clusia schomburgkiana* (7-6%), and *C. inesiana* (7-6%). A total of 41 individuals (shrubby to arboreal strata), 10 species and 1.4 square meters of basal area (BA) were found by plot of 1000 square meters surface.

Geographic distribution: These oak forests grow on the sub-Andean region at 2000 m. The landscapes include steep ridges, and moderately steep ridges with slopes between 50 and 75%.

Conservation status: There are important remnants of these oak forests in the region, but they had been affected by selective logging and a process of degradation and deforestation. The oak forests included inside the Protected Area called Estación Biológica Cachalú show a low degree of human intervention which means a good status of conservation

Large formation dominated by *Q. humboldtii* and *Cyathea multiflora* forests

Table II

Floristic composition and structure: Dominant species are: *Q. humboldtii*, *Ilex laurina*, *Billia rosea*, *Hyeronima huilensis*, *Ladenbergia macrocarpa*, and *Cyathea* cf. *multiflora*. The superior arboreal stratum (As) with low coverage is represented by *Q. humboldtii* (3%), *B. rosea* (1%), *H. huilensis* (1%), and *Podocarpus oleifolius* (1%). In the inferior

arboreal stratum (Ai), *Q. humboldtii* dominates with 21%, followed by *Clusia* cf. *bracteosa* (3%), *B. rosea* (2%), *Alchornea grandiflora* (2%), and *L. macrocarpa* (2%). In the treelets' stratum (Ar), *Q. humboldtii* dominates with 5%, *L. macrocarpa* (4%), *Clusia discolor* (4%), and *Cyathea* cf. *multiflora* (3%). The dominants of the shrubby stratum were *Cyathea* cf. *multiflora* with 3%, followed by *Q. humboldtii* (2%), *L. macrocarpa* (2%), and *C. discolor* (1%). The species with a greater relative IVI (%) and IPF (%) were *Q. humboldtii* (16-22%), *L. macrocarpa* (4-5%), *C. discolor* (4-5%), *Clusia* cf. *bracteosa* (4-5%), *H. huilensis* (4-5%), *A. grandiflora* (4-3%). A total of 79 individuals (shrubby to arboreal strata), 20 species and 3.96 square meters of basal area (BA) were found by plot of 1000 square meters surface.

Geographic distribution: These oak forests grow on the sub-Andean region between 1820 and 2200 m. But plot (LEV-39) was located at 2300 m. The landscapes include moderately steep ridges with slopes between 50 and 75%. The soils are moderately deep.

Conservation status: There are important tracts of these oak forests still, but these forests had been affected by selective logging, process of degradation and deforestation, because the local communities use the oak forests in more intensive way. The human intervention shows a medium degree, which means an intermediate status of conservation.

Forests dominated by *Q. humboldtii* and *Daphnopsis caracasana*

Table II

Floristic composition and structure: Dominant species are: *Q. humboldtii*, *Billia rosea*, *Alchornea grandiflora*, *Daphnopsis caracasana*, and *Clusia multiflora*. The inferior arboreal stratum (Ai) is represented by *Q. humboldtii* dominates with 12%, followed by *D. caracasana* (4%), *Clethra fagifolia* (4%) and *C. multiflora* (4%). In the treelets' stratum (Ar), *Ladenbergia macrocarpa*

dominates with 5%, *Ilex laurina* (4%), *C. fagifolia* (3%), and *Escallonia* cf. *floribunda* (3%). The dominants of the shrubby stratum were *Cyathea* cf. *multiflora* with 5%, followed by *Clusia discolor* (2%), *C. fagifolia* (2%), *D. caracasana* (1%), and *Tibouchina lepidota* (1%). The species with a greater relative IVI (%) and IPF (%) were *Q. humboldtii* (8-10%), *C. fagifolia* (8-9%), *Cyathea* cf. *multiflora* (7-8%), *Clusia discolor* (5-5%), *A. grandiflora* (5-5%), and *C. multiflora* (4-4%). A total of 75 individuals (shrubby to arboreal strata), 18 species and 4.1 square meters of basal area (BA) were found by plot of 1000 square meters surface.

Geographic distribution: These oak forests grow on the Andean region between 2210 and 2600 m. The landscapes include moderately steep ridges and abrupt crests with slopes between 50 and 75%. The soils are moderately deep.

Conservation status: The local communities used intensively these oak forests in the past century. There are important tracts of these oak forests with evidence of selective logging and process of degradation and deforestation. Human intervention shows medium to high degree which means an intermediate status of conservation.

Forests dominated by *Q. humboldtii* and *Pouteria baehniana*

Table II

Floristic composition and structure: Dominant species are: *Q. humboldtii*, *Ilex laurina*, *Pouteria baehniana*, *Spirotheca codazziana*, and *Ladenbergia macrocarpa*. The superior arboreal stratum (As) with low coverage is represented by *Q. humboldtii* (2%), *Billia rosea* (1%), and *P. baehniana* (1%). In the inferior arboreal stratum (Ai), *Q. humboldtii* dominates with 22%, followed by *Clusia* cf. *bracteosa* (3%), *Billia rosea* (2%), *Heyeronia huilensis* (2%), and *Alchornea grandiflora* (2%). In the treelets' stratum (Ar), *Q. humboldtii* dominates with 6%, *Clusia schomburgkiana* (5%), *Clusia* cf. *bracteosa* (4%), *Palicourea* sp. (EHC 366) (4%), *L. macrocarpa* (4%), and *Miconia* cf.

smaragdina (4%). The dominants of the shrubby stratum were *Palicourea* sp. (EHC 366) with 3%, followed by *Q. humboldtii* (1%), *L. macrocarpa* (1%), *Schefflera aff. jahnii* (1%), and *Myrcia popayanensis* (2%). The species with a greater relative IVI (%) and IPF (%) were *Q. humboldtii* (18-24%), *Clusia cf. bracteosa* (5-6%), *L. macrocarpa* (4-5%), *Palicourea* sp. (EHC 366) (4-5%), *H. huilensis* (4-4%), and *A. grandiflora* (4-4%). A total of 80 individuals (shrubby to arboreal strata), 20 species and 3.9 square meters of basal area (BA) were found by plot of 1000 square meters surface.

Geographic distribution: These oak forests grow on the sub-Andean region between 1820 and 180 m. The landscapes include moderately steep ridges with slopes between 50 and 75%. The soils are moderately deep.

Conservation status: These oak forests had been the most affected by the coffee plantations, and currently there are reduced in good conservation status. Human intervention shows medium degree which means an intermediate status of conservation.

KNOWLEDGE OF OAK FORESTS BY LOCAL COMMUNITIES: CONSERVATION AND EXPLOITATION PRACTICES

The demand for wood resources derived from oak forests began in the first half of the 20th century, supported by a series of regulations that permitted the indiscriminate exploitation of forests. The main activities that shaped the current state of the oak forests were: i) the construction of railroad tracks, ii) the manufacture of poles and levers for mining, iii) the selective extraction of valuable wood species such as cedro, comino and pino colombiano (species classified within the genera *Cedrela*, *Ocotea*, *Aniba* and *Podocarpus*) for trade, iv) handmade charcoal, and v) the expansion of livestock activities which accelerated deforestation.

According to interviews with members of local communities, oak forests are considered ecosystems of high cultural and social value. Their direct use values is linked to the domestic supply of firewood and wood (for fences and other products)

required by the family unit. A single family in a rural area uses 5 to 8 tn/year (ca. 10 m³/year) of wood for fuelwood and 5 to 8 m³ of wood for fences and land maintenance (Aristizabal, 2010; Avella & Cardenas, 2010). Most of this wood is obtained from native species including not only *Q. humboldtii* but also aliso (*Alnus acuminata*), amarillo (*Nectandra spp.*, *Ocotea calophylla*), patavaca (*Clethra fibriata*), encenillos (*Weinmannia pubescens*, *W. tomentosa*), cucharos (*Myrsine guianensis*), gaques (*Clusia multiflora*, *C. schomburgkiana*), tunos (*Miconia sp.*, *Blakea cuatrecasii*, *Centronia sp.*), canelo (*Aniba robusta*, *Aniba perutilis*), and, in some cases, introduced species of genera such as *Acacia*, *Eucaliptus* and *Pinus*.

Nonetheless, not only the direct use values are relevant. The protection of watersheds and wildlife fauna as well as the prevention of soil erosion are among the oak forest's indirect use values recognized by the communities. In terms of passive use values, oak trees and oak woods have been linked to the local families' histories for a long time and are the main symbols characterizing the region.

The interviews identified two principle use practices of oaks, for fuel and for land tenure and property maintenance (fence posts, stakes for crops, timber and tool handles). Currently, the substitution of wood products by more expensive hydrocarbon fuels, plastic and metallic fences and other supplies for maintenance is not a financially feasible option in an area where resources to fulfill basic needs are already limited. Consequently, most community members believe that the regulated domestic use of forest stands should be allowed and be accompanied by educational programs and training, and the provision of economic benefits to cover the transition towards the use of alternative fuel options. These programs are deemed necessary for the sustainability of oak forestry.

Local communities have also noticed the loss of biodiversity in oak forests. Due to this, initiatives that seek the restoration and recovery of the original condition of the oak forests will be supported by them. According to Avella & Cárdenas (2010), at this point one has to take into account the knowled-

ge of the local peoples on the methods of propagation, and the establishment, management and harvesting of some species of native forests like harvesting of only over-mature trees, developing of natural regeneration management techniques, and identification and selection of potential species for timber and non-timber products. This life experience could be the appropriated reference for the design of alternative models of conservation and sustainable use of oak forests. Among the alternative actions that suggest local communities with regard to the management and conservation of oak forests, we can cite:

- Conduct forest zoning with the participation of local communities.
- Develop and implement forest management plans to optimize the regulation, planning and exploitation process.
- Conduct pilot studies to define optimal procedures to prevent, regulate, mitigate and compensate for the negative impacts of the exploitation of oak forests in selected areas for sustainable use.
- Strengthening the technical capacity of local communities and institutions to improve the domestic harvesting practices.
- Propose shared management agreements with local communities for conservation and sustainable use of oak forests.
- Promote the allocation of financial incentives referred to in the environmental legislation of the country for local communities in recognition of their efforts to preserve oak forests.
- Develop technology packages for the efficient use of firewood.
- Promotion and implementation of agroforestry and silvopastoral systems to protect soils and water sources.

DISCUSSION

The structural parameter values for number of individuals, number of arboreal species and basal area (Table III) can serve as proxies for conservation status and the possibility of sustainable management for various types of oak forests. To compare among the different parameters, the average values for each were calculated. The results reveal low values for upper tree layer coverage (>25 m), which indicates that most of the oak forests have been intervened to extract the valuable species. The parameter comparison also indicates that forests as *Q. humboldtii* - *V. macrocarpa* and *Q. humboldtii* - *Pouteria baehniiana*, with individuals that are equal to or greater than 20 m in height and that have greater numbers of individuals and species than average ($X = 75$ individuals and $X = 19$ species) can be used by farmers employing sustainable silvicultural practices. Sustainable management practices allow some level of use by local communities but also ensure the protection of these forests that were affected by conversion to coffee plantations. This approach will also help the recovery of endangered species that were affected by selective logging such as *Aniba perutilis*, *Cedrela montana* and *Podocarpus oleifolius*.

Q. humboldtii – *Daphnopsis caracasana* forests have high basal areas, numbers of individuals and numbers of species. Despite the intensive use to which these forests were subjected in the last century, their current extension and conservation status are valid arguments for incorporation into programs for sustainable forest management. *Q. humboldtii* - *Ocotea calophylla* forests, localized in the High-Andean fringe, are noteworthy for their floristic homogeneity and high basal area values. However, this forest type is more important for its ability to regulate hydrological cycles, especially considering that nowadays, there is a clear tendency among forest managers to favor the establishment of rigorous protection policies to preserve water resources. For these reasons, we do not suggest developing forest management programs in these oak forest type. *Q. humboldtii* - *Blakea cuatrecasii* forests should not be subject to any

use, because they have very low numbers of individuals, species and basal area.

Currently, approximately 57 000 ha (30%) of the original 180 000 ha of oak forests still exist in the central area of the conservation corridor. The majority of the forests are on private property, following a strong tendency toward land fragmentation caused by a significant “small landholders” tradition. The oak forests are highly important socially and culturally for the farming communities of the region. The use of these forests is directly related to the need for firewood and wood for domestic uses. Average wood consumption per family is between approximately 15 and 20 m³ by year (Avella & Cardenas, 2010), an amount that is mostly provided by native species associated with oak forests. However, despite the importance of these forests for local communities and institutions, their degradation and deforestation continue. These valuable ecosystems (from a biological perspective) are primarily associated with farming communities, which cover 87% of the territory where oak forests are present. These communities have a strong relationship with the forests, use some of their ecosystem services and follow a series of practices for their use and harvesting. Natural forests of good quality can also offer important environmental services such as carbon storage and the preservation of fauna and flora. These functions can only be preserved through the application of rational management practices such as management of seed trees, establishment of a minimum diameter of cutting, structural retention at the stand level, natural regeneration management, the maintenance of connectivity at the landscape level, the use of knowledge of natural disturbance regimes to guide forest management practices, and techniques to reduce the impact of logging. Implementing these practices could help to maintain the potential of forest resources to produce a complete series of benefits for local communities.

Local knowledge about management and preservation of oak forests has been generated in the region (Avella & Cardenas, 2010), and includes practices such as harvesting of only over-mature trees, development of natural regeneration management

techniques, development of management protocols in native species nurseries, and identification and selection of potential species for timber and non-timber products. Considering the slow development of scientific and technical knowledge about oak forest management, the traditional knowledge of local communities could provide important contributions to the design of management alternatives that could effectively contribute to the preservation and sustainable use of the oak forests present in the region.

CONCLUSIONS

In a continuous altitudinal gradient the oak forests of the Guantiva - La Rusia – Iguaque corridor grow from the sub-Andean region 1900 to 3200 m near the lower limits of the Páramo region, and can be categorized into a hierarchical structure of seven types of forests: *Q. humboldtii* - *Ocotea calophylla* forests, present in the high Andean region (>2200 - 3200 m); the great formation of *Q. humboldtii* - *Alchornea grandiflora* forests, common in the Andean region and which includes the *Q. humboldtii* - *Blakea cuatrecasii* and *Q. humboldtii* - *Cyathea multiflora* forest types; and the *Q. humboldtii* - *Daphnopsis caracasana* and the *Q. humboldtii* - *Pouteria baehniiana* forests. *Virola macrocarpa* - *Q. humboldtii* forests are present in the sub-Andean life zone.

According to our results on floristic and physiognomic characterization, forests with high values in basal area, number of individuals, number of species and average canopy height, such as *Virola macrocarpa* - *Q. humboldtii*, *Q. humboldtii* - *Pouteria baehniiana*, and *Q. humboldtii* - *Daphnopsis caracasana* forests, can be used by the community with technical prescriptions for management of seed trees, establishment of a minimum diameter of cutting, harvesting of over-mature trees, structural retention at the stand level, techniques to reduce logging impacts, natural regeneration management and the maintenance of connectivity at the landscape level, all of which could allow their perpetuation. Oak forests with low richness and basal area values such as *Q. humboldtii* - *Blakea cuatrecasii* forests and forests that provide important hydrological regulation services such as *Q. humboldtii* - *Ocotea calophylla* should not be

Table III. Floristic and structural aspects of the oak forests in the central area of the GRI conservation corridor

Plant formations	Strata coverage (highest)	Height average canopy (m)	Height Max. (m)	No. of Ind. X=75	No. tree species X=19	Basal area (m ²) X=3.4	Dominant species According to relative IVI (%) and IPF (%)	Natural region
<i>Q. humboldtii</i> and <i>Ocotea calophylla</i> forests	Ai 86%, Ar 38%	17	24	83	12	4.6	<i>Q. humboldtii</i> (48; 70), <i>Ocotea calophylla</i> (4; 3), <i>Clusia multiflora</i> (3; 3), and <i>Weinmannia tomentosa</i> (3; 4).	High-Andean fringe (80%) and Andean (20%) Altitudinal limit: 2316 - 3250 m
<i>Q. humboldtii</i> and <i>Virola macrocarpa</i> forests	Ai 52%, Ar 27%	20	30	94	33	3.2	<i>Q. humboldtii</i> (6; 8), <i>Virola macrocarpa</i> (11; 14), <i>Compsoeura rigidifolia</i> (11; 9), <i>Sterigmapetalum tachirensis</i> (3; 4), <i>Faramea flavicans</i> (4; 4), and <i>Billia rosea</i> (3; 3).	Sub-Andean Altitudinal limit: 1850 - 1950
<i>Q. humboldtii</i> and <i>Blakea cuatrecasii</i> forests.	Ai 24%, Ar 10%	13	20	41	10	1.4	<i>Q. humboldtii</i> (42; 59), <i>Blakea cuatrecasii</i> (9; 8), <i>Clusia schomburgkiana</i> (7; 6), and <i>Clusia inesiana</i> (7; 6).	Sub-Andean 2000 m
<i>Q. humboldtii</i> and <i>Daphnopsis caracasana</i> forests	Ai 48%, Ar 50%	13	20	75	18	4.1	<i>Q. humboldtii</i> (8; 10), <i>Clethra fagifolia</i> (8; 9), <i>Cyathea</i> cf. <i>multiflora</i> (7; 8), <i>Clusia discolor</i> (5; 5), <i>Alchornea grandiflora</i> (5; 5), and <i>Clusia multiflora</i> (4; 4).	Andean Altitudinal limit: 2210 - 2600
<i>Q. humboldtii</i> and <i>Pouteria baehniiana</i> forests	Ai 57%, Ar 60%	17	30	80	20	3.9	<i>Quercus humboldtii</i> (18; 24), <i>Clusia</i> cf. <i>bracteosa</i> (5; 6), <i>Ladenbergia macrocarpa</i> (4; 5), <i>Hyeronima huilensis</i> (4; 4), and <i>Alchornea grandiflora</i> (4; 4).	Andean (70%) Sub-Andean (30%) Altitudinal limit: 1800 - 2180

used under any circumstance and should be subject to strict strategies for the protection, restoration and recovery of their biodiversity and ecosystem services.

Due to the cultural and social values that oak forests represent to local communities, and the knowledge and interest in forest management expressed by the communities themselves, it is attractive to consider a strategy of allowing controlled use to satisfy minimum demands for firewood and domestic uses based on models of sustainable development. Therefore, it is necessary to design integral conservation strategies that contemplate not only protection and restoration of biological diversity, maintenance of ecological integrity and protection of soil and water, but also actions that promote to the sustainability of the supply of timber and non-timber products as an essential component. Doing so will consolidate the processes of biodiversity conservation as well as improve the quality of life for the local communities.

The conservation strategy described here should be based on the generation of co-management agreements with local communities, and should receive the strong support of governmental entities, universities, research institutions and local NGOs. This coalition of actors could favor the integral conservation of the oak forests and the improvement of the quality of life of local communities. Various dimensions are recognized in oak forest ecosystems, including the provisioning of natural resources, linkages with adjacent ecosystems, ecosystem services, protection of biodiversity, social and cultural value and natural heritage. Such perspectives provide technical and methodological elements to the new forest management approach that must be implemented in Colombian oak forests following the recommendations of the Ecosystem Approach (Rangel *et al.*, 2002; SCDB, 2004).

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