FINAL REPORT

October 2011

2009 Future Conservationist Award

Project 130609

Project title

"CONSERVATION ASSESSMENT AND ACTION PLAN FOR A THREATENED COLOMBIAN CYCAD"

PROJECT TEAM

Cristina López-Gallego
Professor Universidad de Antioquia (Colombia)

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BirdLife INTERNATIONAL · Wildlife Conservation Society · bp · Conservation International · Fauna & Flora International

Conservation Leadership Programme

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PROJECT ABSTRACT

Zamia encephalartoides is a threatened cycad endemic to a unique ecosystem, the arid Chicamocha Canyon of Colombia. Its distribution and population status are poorly known, and expanding agriculture and other human activities are rapidly extirpating its known populations. With this project we generated high-quality information about the species distribution and abundance and performed a preliminary evaluation of population viability so that an accurate Red List assessment could be produced and a Conservation Action Plan could be proposed with relevant stakeholders interested in the conservation of the species.

LOCATION & DATES OF THE PROJECT

The project is carried out in localities around the Chicamocha river canyon in the eastern chain of the Andes in Colombia (AZE site).
The project started on July 2009 and finished in April 2011 (duration of 22 months).

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SUMMARY OF THE REPORT

Cycads are one of the most threatened groups of plants in the world, but the species status and threats for conservation are poorly known for many cycads. In South America, *Zamia encephalartoides* is one of the least known cycads that inhabits the highly-endangered tropical dry forest of the Chicamocha canyon in Colombia. The main goal of our project was to explore population distribution and abundance and to perform a preliminary evaluation of population viability for *Zamia encephalartoides* to complete a detailed evaluation of the conservation status an suggest and action plan for the conservation of this endangered cycad.

The main achievements to accomplish our goal were:

I. We evaluated the use of high-resolution satellite imagery for identifying large populations and suitable habitat for the species and suggest that the images have limited utility to predict potential sites for field exploration.

II. We identified five main localities with populations for the species, most of which have never been recognized on the Red List assessments for *Zamia* species in Colombia. Two of these localities have populations of ca. 1000 individuals, and the total number of individuals for the species approaches 2500, a number much higher than reported before.

III. With the spatial information we gathered we estimated the extent of occurrence for the species = 360 $km^{2.}$ larger than previoulsy known, and we provided the first estimation of the area of occupancy for the species = 76.5 km^2).

IV. We suggested two main localities with the largest known populations of *Z. encephalartoides* as important sites for conservation and long-term population monitoring. In these two localities we established permanent plots to gather data on plant survival, growth and reproductive rates for exploring population dynamics.

V. Population census data were used to estimate population structure and its growth rate. Population structure showed a large proportion of seedlings and juveniles, suggesting the populations are actively reproducing. Population modelling showed that one of the populations has a positive growth rate, increasing in population size by about 1.5% per year. However, the other population has a slightly negative growth rate, decreasing a 0.8% per year in population abundance. Nevertheless, improving estimates for population models and evaluating annual variation in survival, growth, and fecundity rates of plants is crucial to properly evaluate population viability in the long-term.

VI. We identified seed sources and collected seeds to enrich an ex-situ conservation program at a local botanical garden that will use these seeds for potential reintroduction programs for the species.

With all the information that we gathered with the project, and after interacting with some of the land owners and officers from the local environmental authorities, we elaborated a "Conservation action plan" for *Zamia encephalartoides.* This action plan follows the guidelines from the IUCN "Strategic planning for species conservation" and the "Open standards for the practice of conservation". The conservation action plan includes detailed information on species biology, an evaluation of the current conservation status and threats for the populations, a re-evaluation of the IUCN threat category for the species, and an action plan with objectives, targets, actions, and a proposed monitoring program.

Project:
"CONSERVATION ASSESSMENT AND ACTION PLAN
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PART I

REPORT OF ACTIVITIES

"CONSERVATION ASSESSMENT AND ACTION PLAN FOR A THREATENED COLOMBIAN CYCAD"

BACKGROUND OF THE PROJECT

The distribution and abundance of populations for South American Cycads (Gymnosperms of the Order Cycadales with 10 genera, including the genus *Zamia*) are poorly known, partly due to a paucity of fieldwork in the region (Stevenson et al. 2003). *Zamia encephalartoides* is a recently described cycad species (Stevenson 2001) endemic to tropical dry forests in the Chicamocha river canyon. It is a poorly understood species with only a single scientific paper published about it (Gonzales 2004) and substantially conflicting red list assessments (Stevenson 2009, Galeano et al. 2005). A better understanding of the distribution, abundance, and population viability of this species is required to appropriately assess its conservation status and develop a conservation action plan for its protection. The recommendations of a plan will provide a framework for conservation of this species and will also benefit other associated obligate species such as herbivores, pollinators, and N-fixing bacteria, and other associated biota of the highly threatened dry forests in the Chicamocha canyon of Colombia.

In addition, the tropical dry forest is considered one of the most fragmented, degraded, and poorly understood ecosystems of Colombia (IAvH 1998). The dry forest of the Chicamocha Canyon is identified as a key site by the Alliance for Zero Extinction, housing critically endangered bird species *Amazilia castaneiventris* and *Thryothorus nicefori*. It is also an important area of endemism, housing endemic plant species such as the cycad *Zamia encephalartoides*, the tree *Cavanillesia chicamochae* (Malvaceae), several herbs of *Salvia* (Lamiaceae), and three cactus species of *Melocactus* (Cactaceae) (Albesiano and Fernández-Alonso 2006). Chicamocha national park was established in the canyon in 2007, but it is a small park (650 acres) focused on cultural and sporting activities and does not protect populations of *Z. encephalartoides* or other endagered species.

MAIN AIM AND OBJECTIVES FOR THE PROJECT

The main goal of the project was to explore the distribution and abundance of populations and to perform a preliminary evaluation of population viability for *Zamia encephalartoides* to complete a detailed evaluation of the conservation status an suggest and action plan for the conservation of this endangered cycad.

The objectives of the project were:

I. Evaluate the use of high-resolution satellite imagery to identify large populations and suitable habitats.
II. Locate and map populations and estimate their population density.
III. Estimate the extent of occurrence and area of occupancy for the species.
IV. Identify large populations as key sites for protection, research, and long-term monitoring.
V. Evaluate population viability by exploring the reproductive effort and recruitment dynamics of the largest populations.
VI. Contribute to ex-situ conservation and re-introduction programs.

CLP research team taking data on *Zamia encephalartoides* in habitat

PHASES OF THE PROJECT: METHODS & MAIN ACHIEVEMENTS

→ Phase I = Pre-field developments

I. Evaluation of the use of satellite imagery to locate cycad populations and to characterize potential suitable habitat for the species to guide field surveys.

The research team obtained a private donation (made effective through Montgomery Botanical Center) for the purchase of 600 sq. km of Quickbird imagery, the highest resolution commercially available satellite imagery currently available (70 cm panchromatic and 2.8 m multispectral resolution). We used the satellite imagery to test the feasibility of using it for locating cycad populations by looking at geographic locations where individual plants had been mapped in our past field work. A variety of vegetation index rasters (NDVI, SQRT, IR-R, TNDVI, VEG) were analysed from the satellite imagery using ERDAS Imagine software.

We found that the spectral signatures of dense *Zamia encephalartoides* clumps were not unique enough to identify them as distinct from surrounding vegetation. All previously known populations of *Zamia encephalartoides* occurred in full sun, which led us to believe that satellite imagery would be useful for locating populations. However, during the course of our first field trip in this project we discovered a large, previously unknown population which occurred under dense dry forest canopy, therefore further limiting the value of using satellite imagery to locate populations. Although the utility of the satellite imagery for locating populations was limited, it was extremely useful for locating promising vegetated areas to survey in the field, for planning routes, for mapping geographic features in GIS, and for georeferencing populations observed at a distance with binoculars.

→ Phase II = Field trips and data collection

II. Location and mapping of populations & Estimation of population sizes.

We reviewed several Herbaria in Colombia and other countries and contacted several Colombian researchers with interest in cycad conservation to list all localities where populations of *Zamia encephalartoides* have been reported and to identify potential sites with suitable habitat for the species. This information was gathered within the first months of the project, after which we started the field work for our project. Within this project four field trips were carried out in December 2009, July 2010, December 2010, April 2011. During these trips we performed extensive field surveys around the potential

localities for the species and counted all adult individuals (or clumps of adults) of *Z. encephalartoides* we could observe registering GPS coordinates for groups of adults.

During the field surveys we were able to identify two main localities with large populations of *Z. encephalartoides* that were previously not reported for the Red List categorization of the species: the Umpala river canyon (near Umpalá & Pescadero, Piedecuesta Municipality) and the Quebrada del monte canyon (near Chocoa, Giron Municipality). In addition to these two sites we located another two sites and the local environmental authorities reported to us another site with small groups of adult plants around the Chicamocha river canyon (near Cepita town, Cepita Municipality), the Guaca river canyon (near La-Habana, Laguna-de-los-Santos Municipality), and Calicho site (near Llanadas, Los-Santos Municipality). All five sites are in the large region of the Chicamocha canyon in the Santander Province of Colombia (see map of visited localities below).

Using counts for adult individuals in the field surveys we estimated the total "adult population size" (sensu IUCN 2001). In the Chicamocha river-Cepita, Guaca river canyon, and Calicho localities we registered less than 300 individuals in total. In the other two localities, the Umpala river and Quebrada del monte canyons, we identified the two main large populations of *Z. encephalartoides* known so far, that were previously unregistered for Red List assessments. The two main populations we found had more than 2000 individuals. Taking all this into account, our current estimate of the total population size for the species is close to 2500 adults.

The previous official Red List categorization for the species recognized only small groups of adults of the species in a few sites around the Umpala river canyon (not including the sites where the largest groups of plants have been located in our project), and considered the species as Critically endangered (the Colombian Plant Red List assessment) assuming very small population sizes (actual estimates were not provided in the assessment) and a small geographical range for the species (less than 100 km^2 for the extent of occurrence).

III. Estimation of the extent of ocurrence and area of ocupancy for the species.

To estimate geographic distribution parameters for the species we counted and mapped adult plants using a handheld GPS in all visited localities. Distant groups of individuals occurring in inaccessible areas such as cliff faces were photographed and later counted by examining the photographs. The populations were georeferenced by comparing the GPS coordinates and photographs with georeferenced high resolution Satellite imagery (Quickbird, 70 cm panchromatic and 2.8 m multispectral resolution) using ArcGis software. Species distribution modelling was carried out using Maxent software (Phillips et al. 2006) with georeferenced presence locality points. The environmental layers used in the analysis included the set of 19 bioclimactic variables as well as altitude from the

Worldclim database (Hijmans et al. 2005). The most important environmental variables contributing to the model were “precipitation of wettest quarter” (with a 70% contribution) and “mean diurnal range” (with a 14.5% contribution), with all additional variables contributing less than 5% to the model. This implies that the low rainfall in the Chicamocha Canyon occurring during the rainiest quarter is the primary limiting factor to the distribution of *Z. encephalartoides.*

With the geographical distribution information for the species we calculated the extent of occurrence and area of occupancy for *Zamia encephalartoides.* The extent of occurrence is defined by the IUCN Red List categorization as the area contained within the shortest continuous imaginary boundary that can be drawn to encompass all known sites of present occurrence for the species or taxon, while the area of occupancy is defined as the actual area within the extent of occurrence for the species occupied by populations. We determined the area of occupancy using the $1/10^{th}$ maximum inter-point distance circular buffer method (Rivers et al. 2010). Individual features created in the analysis were considered subpopulations (sensu IUCN) and their combined area was used to determine the area of occupancy for the species. The extent of occurrence was determined by drawing a polygon around the populations and determining the total area.

In the case of *Z. encephalartoides* the known populations are spread in an area of 360 km^2. This estimated extent of occurrence is significantly larger that the previous estimate for the species used in the Red List assessment performed for all *Zamia* species of Colombia of 100 km^2. The area of occupancy for the *Z. encephalartoides* taxon is 76.5 km^2, and was previously undetermined for the species in the Red List categorization.

IV. Choosing localities for conservation and long-term research of population dynamics.

After the field surveys we performed we chose two sites with the largest known populations for *Z. encephalartoides* as sites for long-term monitoring of population dynamics: the Umpala river and Quebrada del monte canyons. The population in the Umpala river canyon is spread mainly in three large groups of individuals in "mesetas" (i.e. flat tops in between small canyons around the main river) and other smaller groups in canyons or slopes besides the Umpala river. The population in the Quebrada del monte canyon is less spread in the locality, with most of the adult individuals distributed on a slope along the river canyon.

Within these two sites we choose sites with high adult density and established 400 m^2 plots (20 x 20 m). We established several plots in each site to ensure that at least 100 adult clumps and 500 juvenile/seedlings were contained within them (6 plots in Umpala river and 2 plots in Quebrada del monte localities). Within the plots we marked all adults, juveniles, and seedlings for long-term demographic monitoring.

V. Evaluation of population viability using data from population censuses.

We marked a total of 152 adults and 449 juvenile/seedlings in the Umpala-river population and 106 adults and 775 juvenile/seedlings in the Quebrada-del-monte population. To establish the population structure we collected data on plant size (using the variables stem size, number of leaves and leaflets) for all individuals. We defined size classes using the number of leaflets. We also defined developmental-stages using all the plant size data. We then constructed population structure graphs using the proportion of individuals belonging to each size class or stage class. The population size structure in both populations showed a typical "inverse J" shape, where most of the individuals in the population are represented in the smaller size classes, suggesting that these populations are actively reproducing and recruiting individuals.

We constructed a model of the life cycle for the species using the developmental stages. To explore population dynamics in a 12 month period, we recorded survival and growth rates for all individuals one year after initially marked in the plots. During the same period we also estimated average annual fecundity values for each population, and estimated germination rates. These data were used to estimate transition probabilities between stages and to build a matrix model to estimate the population growth rate -λ- (using standard techniques for matrix projection modelling, Caswell 2001). The population modelling showed that the population in the Quebrada del monte canyon has a positive growth rate (λ=1.015), while the population in the Umpala river canyon has a slightly negative growth rate (λ=0.992). The population in the Quebrada del monte canyon has lower seed production (fecundity), but higher seed germination, and seedling and juvenile survival than the population in the Umpala river canyon.

The preliminary estimation of the population growth rate suggests that the population in the Quebrada del monte canyon populations is currently viable from a demographic point of view, but the population in the Umpala river canyon could be less viable and might need some management. Nevertheless, our population analyses are only preliminary for exploring population dynamics, since our estimates were based on data from a one-year monitoring. One year of data for a plant with a generation length of decades (suspected) and large fluctuations in fitness of individuals (survival, growth, fecundity) among years is not enough to make accurate predictions on population dynamics for the near future. Only long-term monitoring of the populations can provide detailed data of inter annual variation on plant fitness that will allow us to properly characterize the dynamics of the populations and construct population models useful to evaluate potential management and conservation strategies for the species.

VI. Contribution to ex-situ conservation programs for the species.

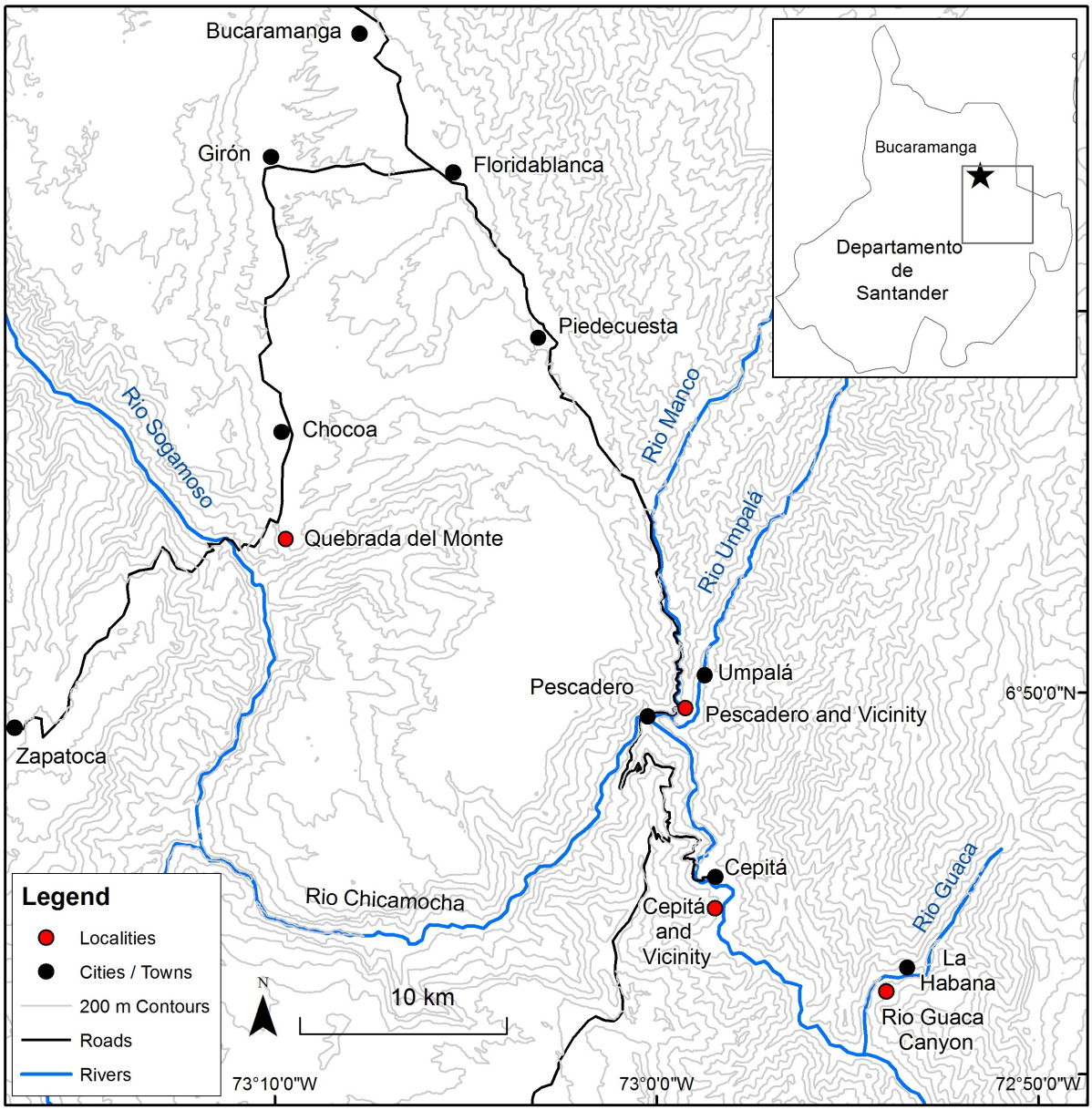
We chose reproductive individuals from the the two largest populations of *Z. encephalartoides* we found and collected female cones from them (Umpala river and Quebrada del monte canyons). We collected a total of 10 female cones from individuals in the two populations, which represented more than 1000 seeds. The seeds were donated to enrich the ex-situ collection of the local botanical garden managed by the local environmental authority (the Jardín Botánico Eloy Valenzuela of the CDMB). The botanical garden have germinated the seeds and the obtained seedlings will be used by the botanical garden for potential re-introduction programs in the original locations of *Z. encephalartoides* where this study was carried out.

→ Phase III = Post-field activities

Summarizing information to elaborate a detailed evaluation of conservation status for the species and to propose an action plan for the conservation of the species.

With all the information that we gathered with the project, and after our multiple interactions with some of the land owners (small farmers or "campesinos") and some officers from the local environmental authorities (the CAR in the region of Colombia: Corporacion para el Desarrollo de la Meseta de Bucaramanga CDMB), we elaborated a "Conservation action plan" for *Zamia encephalartoides.* This action plan follow the guidelines from the IUCN "Strategic planning for species conservation" (IUCN/SSC 2008), and we used also the "Open standards for the practice of conservation" (CMP 2007) that many conservation organizations are currently using for conservation planning. The conservation action plan includes detailed information on species biology, an evaluation of the current conservation status and threats for the populations, a re-evaluation of the IUCN threat category for the species, and an action plan with objectives, targets, actions, and a proposed monitoring program.

Localities visited where groups of adult individuals of *Zamia encephalartoides* were registered



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Project:
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PART II

CONSERVATION ACTION PLAN FOR *Zamia encephalartoides*

CONSERVATION ACTION PLAN FOR *Zamia encephalartoides*

CONTENTS [+]

+ This conservation action plan follows the recommendations in : IUCN/SSC -Species Survival Commission 2008. *Strategic Planning for Species Conservation: An Overview; version 1.0.* IUCN Gland, Switzerland.

1. INFORMATION ON SPECIES BIOLOGY

SPECIES DESCRIPTION	
Historical account	A seed cone of *Zamia encephalartoides* were illustrated during the "Real Expedición Botánica del Nuevo Reyno de Granada" (The Royal Botanical Expedition of the New Kingdom of Granada) led by José Celestino Mutis from 1783-1816). The species appears to have been lost to science until 1948, when it was collected in Santander by Jorge Araque Molina and Fred A. Barkley (#18S.273 at COL, MEDEL, USA). Several botanical collections have occurred in the last three decades, but the species was not officially described until 2001 (Stevenson 2001). The species appears similar to species of the genus *Encephalartos,* an African genus that typically grows in similar open, dry environments. In fact, the specific epithet for *Zamia encephalartoides* means "*Encephalartos*-like".
Vegetative features	Plants arborescent, stems solitary or cespitose to 2 m long and 20-30 cm in diameter, each trunk carrying 1-30 leaves up to 135 cm long with up to 40 leaflet pairs. Leaflets coriaceous, lanceolate, with entire margins, to 35 cm long and 3 cm wide.
Reproductive features	Seed cones typically solitary, but individual stem apices can sometimes hold up to four cones produced in different seasons. Cream to yellow tomentose when juvenile, dark green to dark brown and glabrous at maturity, cylindrical to ovoid-cylindrical in shape, 25 to 48 cm long, 10-15 cm in diameter, sporophylls spirally arranged in 8-14 orthostichies of 4-15 megasporophylls each, appearing sessile with short peduncle to 3 cm long by 4 cm in diameter. Seeds with cream or yellow sarcotesta at maturity, ovoid to ovoid pyramidal, 30-40 mm long by 17-22 mm in diameter, sclerotesta light brown and smooth, ovoid to ovoid pyramidal, 17-36 mm long by 17-20 mm in diameter.
Habitat	Unlike most other Colombian species of *Zamia* which typically occur in the forest understory in areas of high rainfall, *Zamia encephalartoides* is remarkably adapted to an open, dry environment. With its extremely coriaceous leaflets, and large, colourful cones it resembles Cycad species from xeric habitats in Africa (from the genus *Encephalartos*). In Colombia, the species is found on hills and canyons in the region of the Chicamocha river valley in the Santander province of Colombia. This Chicamocha valley region is dominated by dry-forest and other xerophytic vegetation ecosystems. Individuals of *Z. encephalartoides* are typically found on slopes of river/stream canyons or nearby hills growing in small to large groups (ca. 10 - 400 plants). Most known populations (including the Umpala river canyon population) grow on hills with sparse xerophytic vegetation, but one population (Quebrada del monte canyon) grows in the understory of dry-forest in rocky hills (see the list of species in the plant community at sites with *Z. encephalartoides* populations).

SPECIES DESCRIPTION	
Resource assessment	*Z. encephalartoides* usually grows on steep, dry, rocky and sandy soils at full sun exposure or under the sparse canopy of dry-forest. As all cycads, this species has close associations with nitrogen-fixing bacteria that form nodules in their roots, with beetle pollinators (yet to be identified), and with a specialist butterfly herbivore (*Eumaeus* sp, Lycaenidae). We found a moss (*Fabronia ciliaris* -Fabroniaceae) growing on leaves of *Z. encephalartoides.*

Most important species of plants and fungi in the ecological community at sites with the two main populations of *Zamia encephalartoides*

FAMILY	Genus and species
Plants	
ACANTHACEAE	*Justicia bracteosa*
ACANTHACEAE	*Justicia candelaria*
ACANTHACEAE	*Ruellia sp*
ALSTROEMERIACEAE	*Eucharis sp*
APOCYNACEAE	*Calotropis procera*
APOCYNACEAE	*Rauvolfia tetraphylla*
APOCYNACEAE	*Stemmadenia grandiflora*
ARACEAE	*Anthurium sp*
BORAGINACEAE	*Cordia divaricata*
BORAGINACEAE	*Heliotropium fruticosum*
BORAGINACEAE	*Varronia curasavica*
BORAGINACEAE	*Wigandia urens*
BROMELIACEAE	*Tillandsia recurvata*
BURSERACEAE	*Bursera simarouba*
CACTACEAE	*Melocactus pescaderensis*
CACTACEAE	*Opuntia pennelli*

FAMILY	Genus and species
CACTACEAE	*Stenocereus griseus*
CAPPARACEAE	*Capparis sp*
COMMELINACEAE	*Callisia repens*
CONVOLVULACEAE	*Evolvulus sp*
EUPHORBIACEAE	*Acalypha cuspidata*
EUPHORBIACEAE	*Euphorbia hirta*
EUPHORBIACEAE	*Jathropa gossypifolia*
FABACEAE	*Acacia farnesiana*
FABACEAE	*Clitoria falcata*
FABACEAE	*Crotalaria sp*
FABACEAE	*Platymiscium pinnatum*
FABACEAE	*Prosopis juliflora*
FABACEAE	*Senna pallida*
HERNANDIACEAE	*Gyrocarpus americanus*
MALVACEAE	*Ayenia magna*
MALVACEAE	*Cavanillesia chicamochae*
MALVACEAE	*Pavonia sp*
MALVACEAE	*Sida abutifolia*
MALVACEAE	*Waltheria indica*
OXALIDACEAE	*Oxalis latifolia*
PIPERACEAE	*Peperomia galioides*
POLYGONACEAE	*Ruprechtia ramiflora*
PORTULACACEAE	*Portulaca pilosa*
RUBIACEAE	*Borreria sp*
RUBIACEAE	*Chomelia sp*
RUBIACEAE	*Randia aculeata*
RUTACEAE	*Zanthoxylum fagara*
SALICACEAE	*Casearia tremula*
SAPINDACEAE	*Cardiospermum coluteoides*

FAMILY	Genus and species
SELAGINELLACEAE	*Selaginella sp*
SOLANACEAE	*Cnidosculus tubulosus*
SOLANACEAE	*Solanum crotonifolium*
STERCULIACEAE	*Melochia mollis*
TURNERACEAE	*Turnera diffusa*
URTICACEAE	*Pilea microphylla*
VERBENACEAE	*Bouchea prismatica*
VERBENACEAE	*Lantana canescens*
VERBENACEAE	*Lippia origanoides*
VERBENACEAE	*Stachytarpheta sp*
Fungi	
AGARICACEAE	*Cyathus striatus*
AMANITACEAE	*Amanita sp*
MARASMIACEAE	*Crinipellis sp*
MARASMIACEAE	*Marasmius sp*
STROPHARIACEAE	*Pholiota sp*

Vegetation growing in *Z. encephalartoides* habitat in Umpala

TOTAL POPULATION SIZE (for the species)	**~ 2433 observed adults**

KNOWN POPULATIONS * (Dpto. Santander, Colombia[&])	**# adults observed ** **	**map**
Umpala river canyon (Umpala & Pescadero, Mpio. Piedecuesta)	1177	1 & 2
Quebrada del monte canyon (Chocoa, Mpio. Giron)	~ 1000	na
Chicamocha river canyon (Cepita town, Mpio. Cepita)	110	3
Guaca river canyon (La Habana, Mpio. Laguna de los Santos)	46	4
Calicho (Llanadas, Mpio. Los Santos)	~ 100	na

* equivalent to subpopulations for IUCN categorization (IUCN 2001)

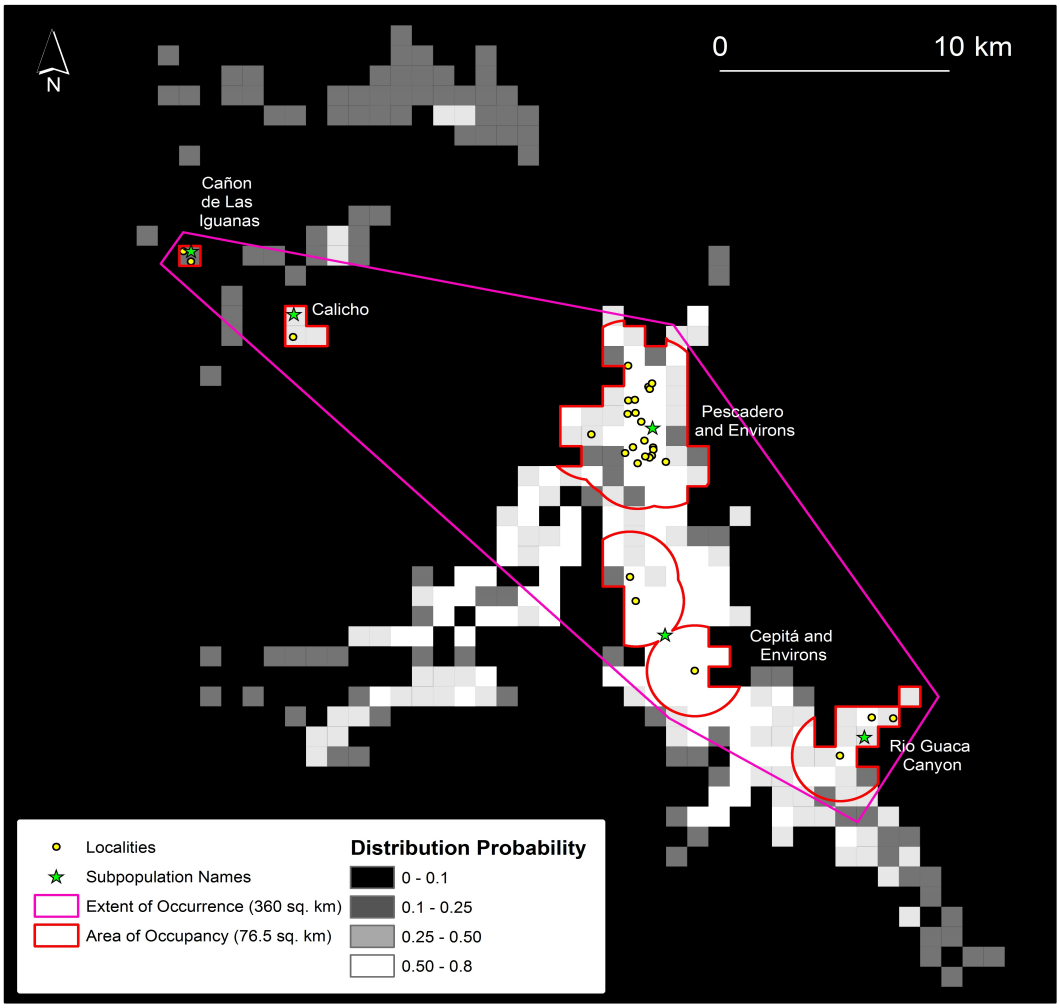
** values obtained by direct counts of groups of adults during field surveys, except for Quebrada del monte and Calicho where an estimated guess was performed

***Zamia encephalartoides* habitat in the Umpala locality**

& Colombia is divided in 32 provinces or states = Departamento -Dpto-
each Province is divided into Municipalities = Municipio -Mpio-
Municipalities may be further divided into Corregimientos o Veredas (we give town names for these)

SPATIAL DISTRIBUTION	estimated parameter ♦
EXTENT OF OCCURRENCE -EOO	360 km^2
AREA OF OCCUPANCY -AOO	76.5 km^2
Elevation range	600-1000 masl

Extent of occurrence & Area of occupancy for *Zamia encephalartoides* using Species distribution modelling (with Maxent software)



♦ METHODS FOR ESTIMATING DISTRIBUTION PARAMETERS

We counted and mapped adult plants using a handheld GPS in all visited localities. Distant groups of individuals occurring in inaccessible areas such as cliff faces were photographed using a telephoto lens and the plants were later counted by examining the photographs in Photoshop. The GPS coordinates, direction, and approximate distance of these populations was recorded, and the populations georeferenced by comparing the GPS coordinates and photographs with georeferenced high resolution Satellite imagery (Quickbird, 70 cm panchromatic and 2.8 m multispectral resolution) using ArcGis software. Species distribution modelling was carried out using Maxent software[+] with georeferenced presence locality points. The environmental layers used in the analysis included the set of 19 bioclimactic variables as well as altitude from the Worldclim database[++]. The most important environmental variables contributing to the model were "precipitation of wettest quarter" (with a 70% contribution) and "mean diurnal range" (with a 14.5% contribution), with all additional variables contributing less than 5% to the model. This implies that the low rainfall in the Chicamocha Canyon occurring during the rainiest quarter is the primary limiting factor to the distribution of *Zamia encephalartoides*.

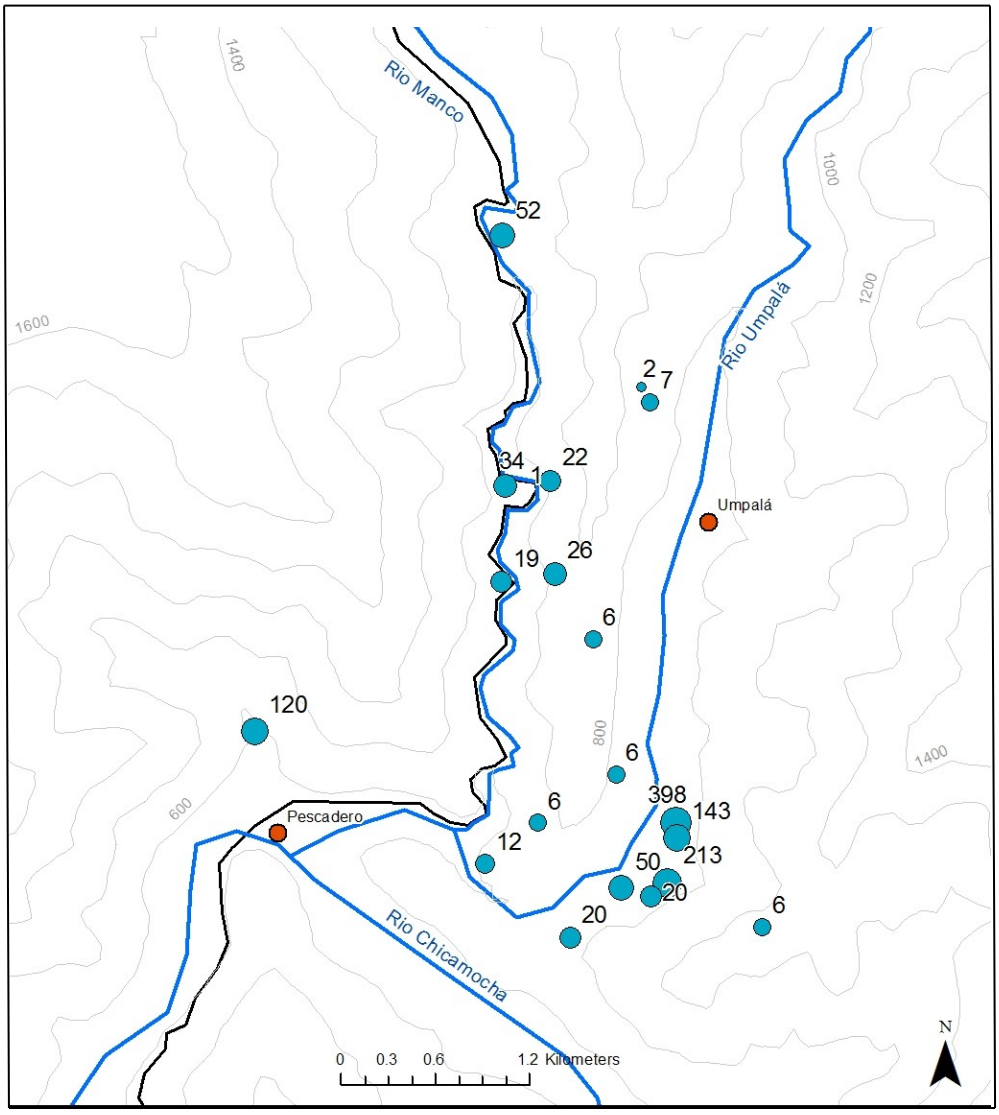
We determined the area of occupancy using the $1/10^{th}$ maximum inter-point distance circular buffer method (Rivers et al. 2010[+++]). Based on the maximum inter-point distance, buffers with a radius of 2.1 km were created around the presence locality points in ArcGIS software with overlapping buffers dissolved into single features. Unsuitable habitat was removed from the resulting features by clipping areas with a Maxent distribution probability below 0.01. Individual features created in the analysis were considered subpopulations (sensu IUCN) and their combined area was used to determine the area of occupancy for the species. The extent of occurrence was determined by drawing a polygon around the populations and determining the total area.

+ Maxent version 3.3.3. Phillips, S. J., Anderson, R. P., Schapire, R. E. 2006. *Maximum entropy modeling of species geographic distributions.* Ecological Modelling 190: 231-259.

++ Hijmans, R.J., Cameron, S.E., Parra, J.L., Jones, P.G., Jarvis, A. 2005. *Very high resolution interpolated climate surfaces for global land areas.* International Journal of Climatology 25: 1965-1978.

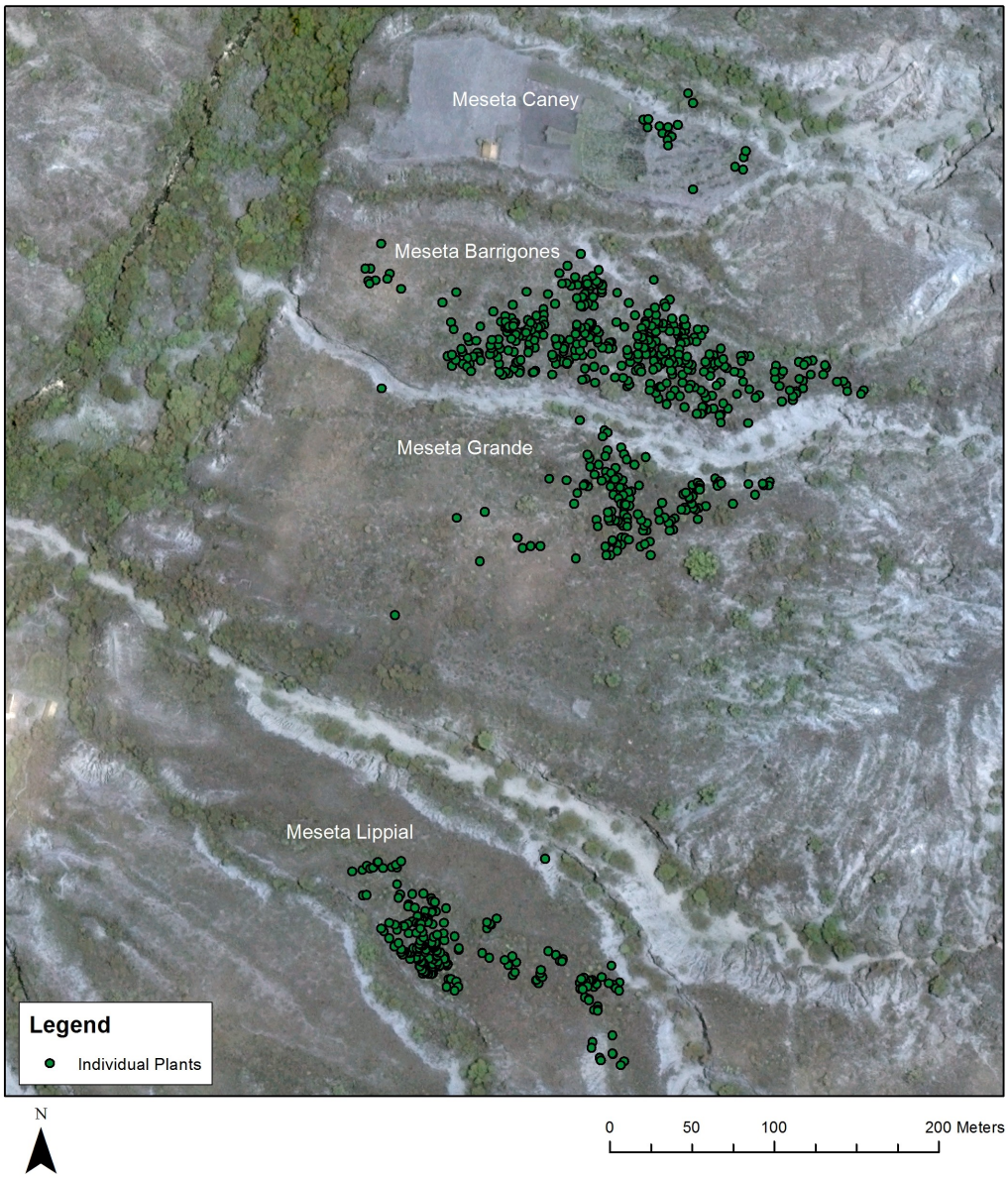
+++ Rivers, M.C., Bachman, S.P., Meagher, T.R., Lughadha, E.N., Brummitt, N.A. 2010. *Subpopulations, locations and fragmentation: applying IUCN red list criteria to herbarium specimen data.* Biodiversity and Conservation 19: 2071-2085.

Map 1. Groups of adults in the Umpala river canyon locality. Total # adults = 1177
(Umpala & Pescadero, Municipio Piedecuesta, Departamento Santander, Colombia)

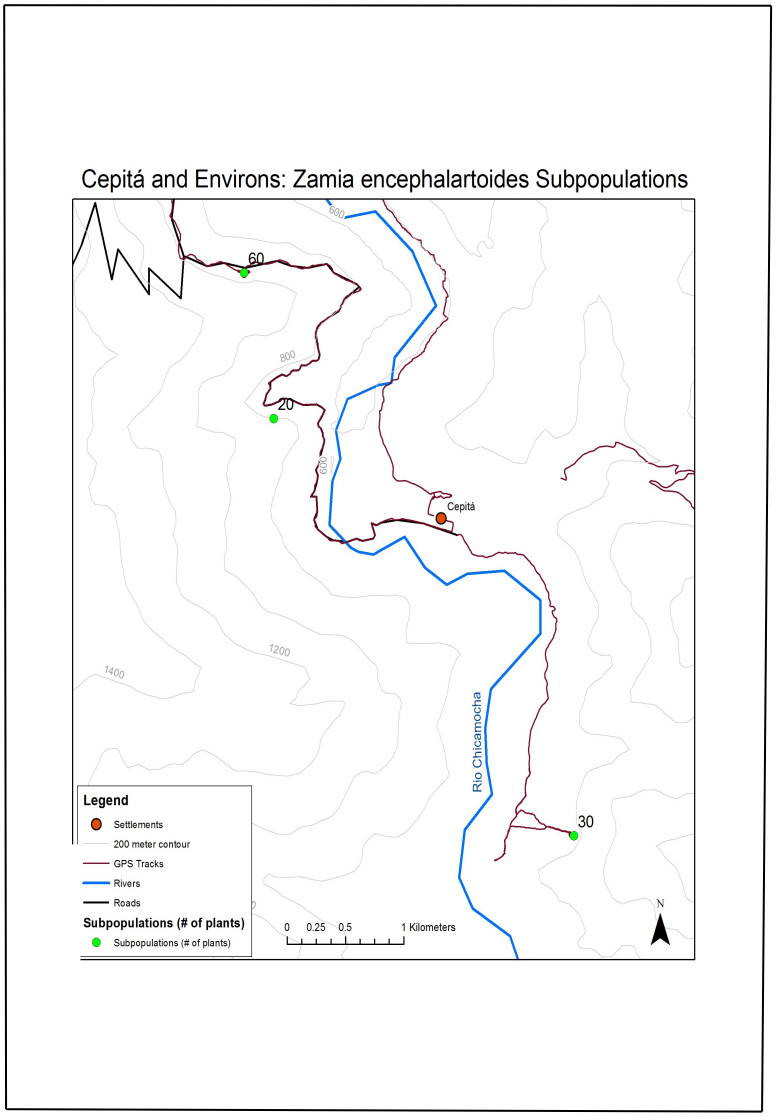


blue circles with numbers correspond to the number of adult groups counted at those coordinates
red circles correspond to towns (within Municipalities -Municipios)

Map 2. Individual plants maped in the Umpala river canyon locality in "Mesetas"
(Umpala & Pescadero, Municipio Piedecuesta, Departamento Santander, Colombia)

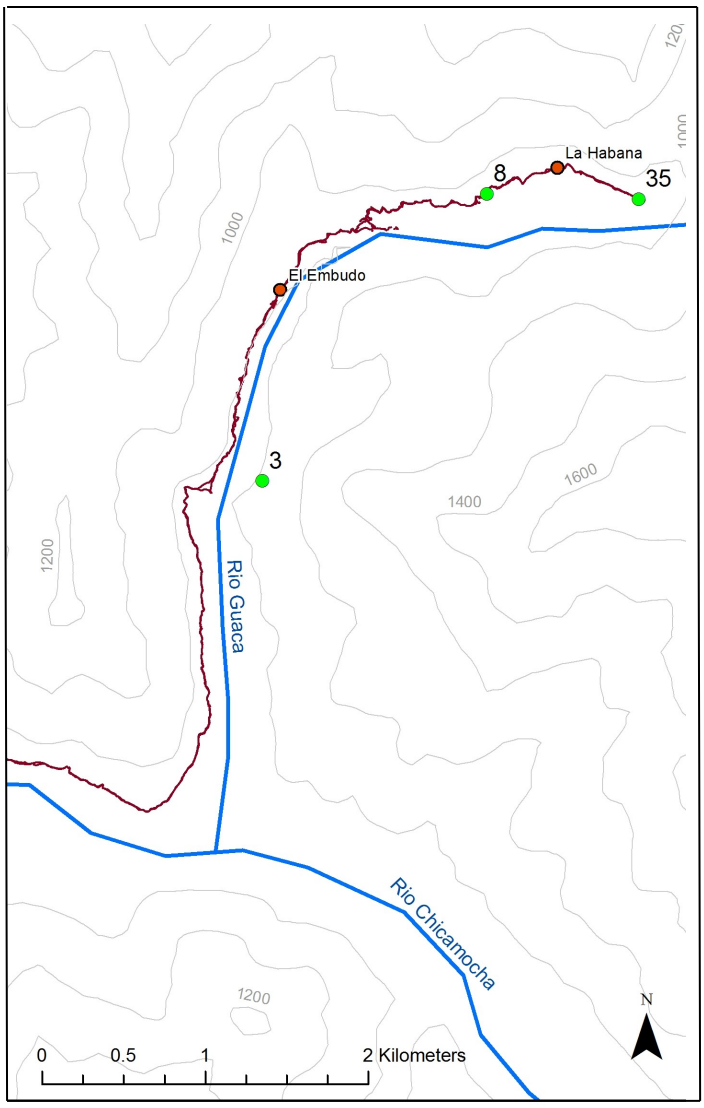


Map 3. Groups of adults in the Chicamocha river canyon locality. Total # adults = 110
(near Cepita town, Municipio Cepita, Departamento Santander, Colombia)



green circles with numbers correspond to the number of adult groups counted at those coordinates
red circles correspond to towns (within Municipalities -Municipios)

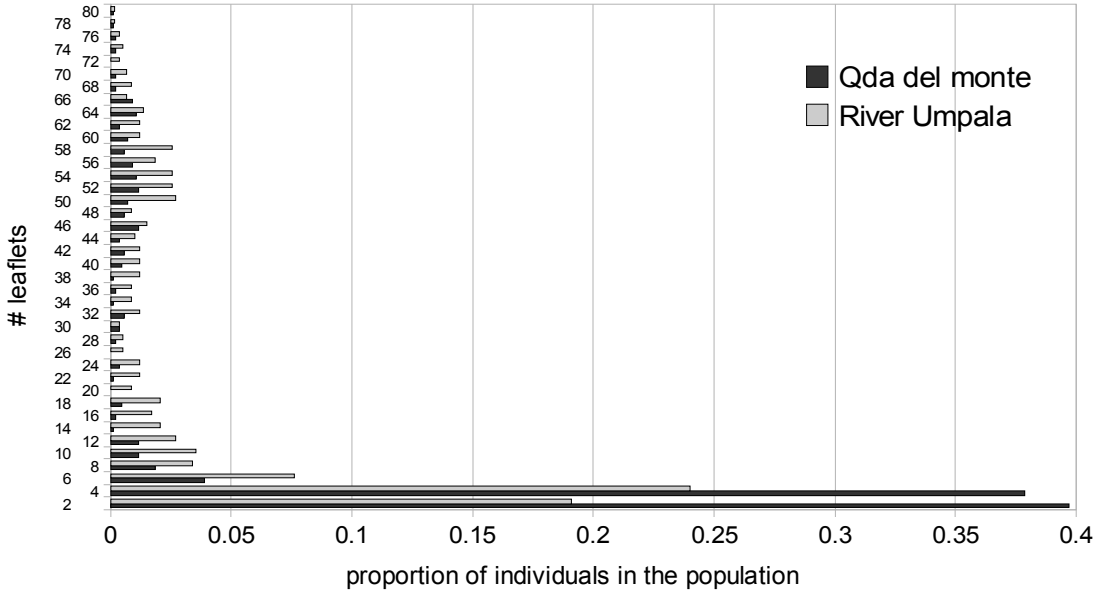
Map 4. Groups of adults in the Guaca river canyon locality. Total # adults = 46
(La Habana, Municipio Laguna de los Santos, Departamento Santander, Colombia)



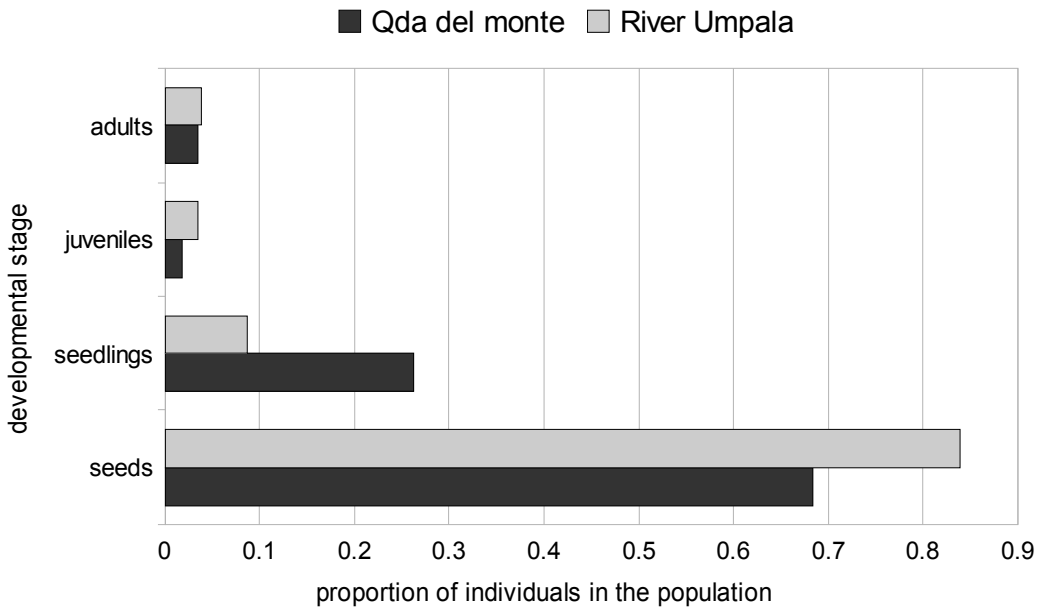
green circles with numbers correspond to the number of adult groups counted at those coordinates
red circles correspond to towns (within Municipalities -Municipios)

POPULATION STRUCTURE	according to size classes & to developmental stages ♣

Distribution of size classes for the two largest populations of *Zamia encephalartoides*

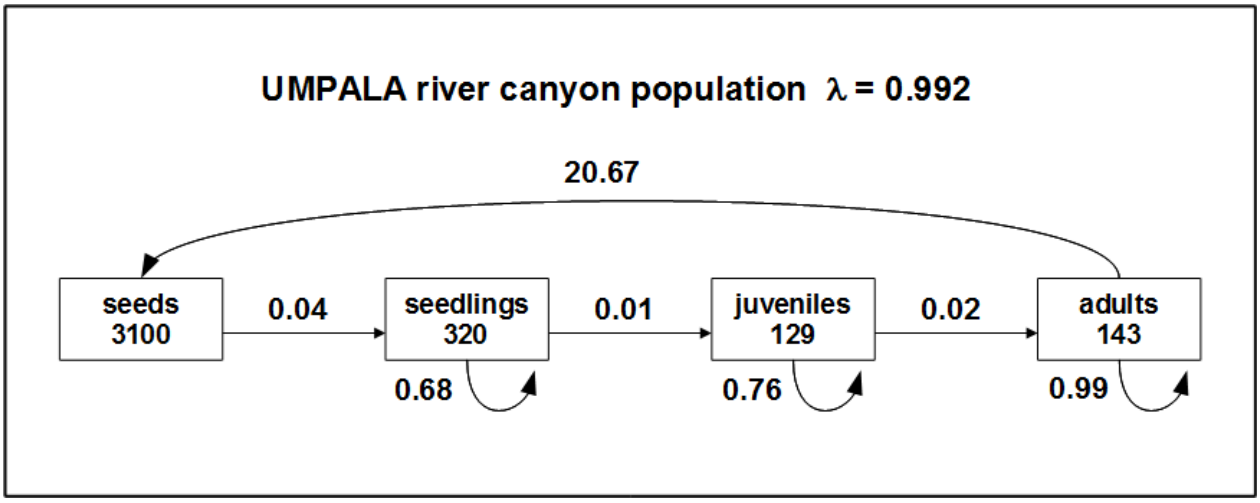


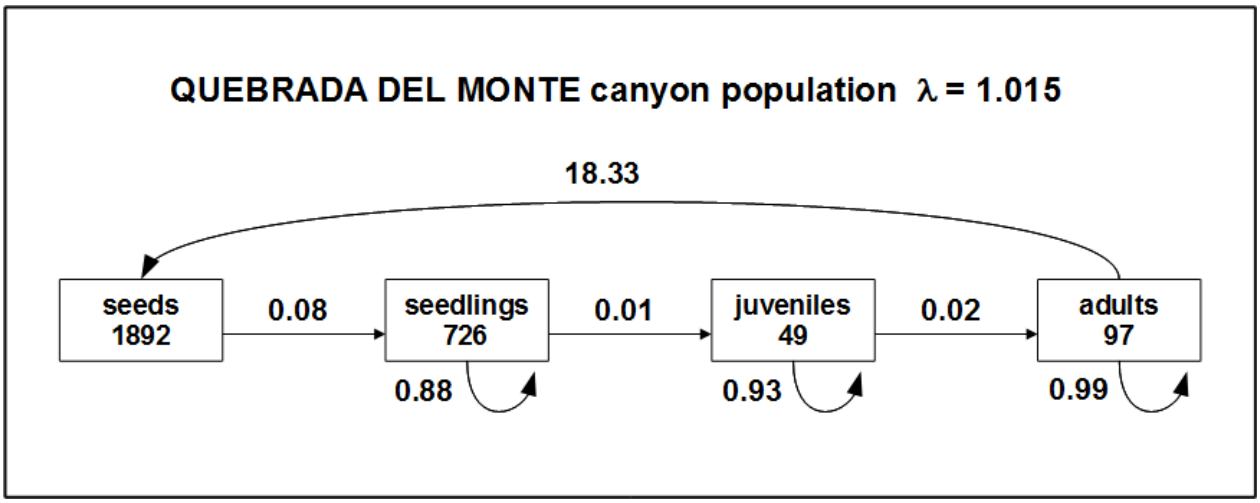
Distribution of stages for the two largest populations of *Zamia encephalartoides*



POPULATION DYNAMICS	using the life cycle model & matrix projection modelling ♣

Life-cycle models with estimates for the population model and λ for the two largest populations of *Zamia encephalartoides*





- number inside boxes represent the number of individuals in that stage
- numbers next to arrows represent probabilities for transitions between stages :
  growth into the next stage & stasis at the same stage
  fecundity = average number of seeds produced by the adults

♣ METHODS FOR EXPLORING POPULATION STRUCTURE & DYNAMICS

In the two largest known populations of *Zamia encephalartoides* (Umpala river and Quebrada del monte canyons) we choose sites with high adult density and established 400 m^2 plots (20 x 20 m). We established several plots in each site to ensure that at least 100 adult clumps and 500 juvenile/seedlings were contained within them. Within the plots we marked all adults, juveniles, and seedlings for long-term demographic monitoring.

To establish the population structure we collected data on plant size (using the variables stem size, number of leaves and leaflets) for all individuals. The adults can form clumps of several stems that can belong to different individuals (i.e. genotypes), therefore we choose the largest stem in each clump to take the data. We defined size classes using the number of leaflets. We also defined three developmental-stages using the plant size data: seedlings, juveniles, adults. We then constructed population structure graphs using the proportion of individuals belonging to each size class or stage class.

We constructed a model of the life cycle for the species using the developmental stages: seeds, seedlings, juveniles, adults. To explore population dynamics in a 12 month period, we recorded survival and growth rates for all individuals one year after initially marked in the plots. During the same period we also recorded all females plants that produced seeds and estimated average seed production/female to obtain average annual fecundity values for each population. We estimated germination rates in two ways: we performed a germination experiment in the field where we planted the total number of seeds from four cones and registered the seedlings that germinated in the following 6 months, and we calculated the rate using the total number of seeds and the new seedlings observed in a year of monitoring. These data were used to estimate transition probabilities between stages: advancing to following stage = growth, staying in the same stage = stasis, return to a previous stage = regression, contributing to stage seeds = fecundity. Transition probabilities in turn were used to build a matrix model to estimate the population growth rate -λ- (using standard techniques for matrix projection modelling, Caswell 2001[+]).

+ Caswell H. 2001. *Matrix population models: Construction, analysis and interpretation; 2nd edition*. Sinauer Associates Massachusetts, USA.

PRELIMINARY EVALUATION OF POPULATION VIABILITY

Analysis from population structure & dynamics data

The population size structure in both populations showed a typical "inverse J" shape, where most of the individuals in the population are represented in the smaller size classes. This pattern in the population structure suggests that these populations are actively reproducing and recruiting individuals. In the other hand, the population modelling showed that the population in the Quebrada del monte canyon has a positive growth rate (λ=1.015), increasing in population size by about 1.5% per year. However, the population in the Umpala river canyon has a slightly negative growth rate (λ=0.992), decreasing a 0.8% per year in population abundance. The population in the Quebrada del monte canyon has lower seed production (fecundity), but higher seed germination, and seedling and juvenile survival than the population in the Umpala river canyon. Most of the populations that we have observed are in hills and canyons wirh sparse scruby vegetation and plant grow at full sun-exposure, like the population in the Umpala river canyon. In contrast, the Quebrada del monte canyon population grows on hills covered by dry-forest vegetation, where most plants are covered by the forest canopy, which could represent environmental conditions where plants have higher rates of survival (although lower rates of reproduction perhaps).

These population parameter data suggest that the population in the Quebrada del monte canyon populations is currently viable from a demographic point of view, but the population in the Umpala river canyon could be less viable and might need some management.

Recommendations for further evaluation of population viability

Our population analyses are only preliminary for exploring population dynamics, since our estimates were based on data from a one-year monitoring. One year of data for a plant with a generation length of decades (suspected) and large fluctuations in fitness of individuals (survival, growth, fecundity) among years is not enough to make accurate predictions on population dynamics for the near future. Only long-term monitoring of the populations can provide detailed data of inter annual variation on plant fitness that will allow us to properly characterize the dynamics of the populations and construct population models useful to evaluate potential management and conservation strategies for the species. We particularly suggest improving the estimates for the germination rate and the adult survival rate, but also to obtain estimates on the magnitude of the variation in survival, growth, and fecundity of all life-cycle stages between years.

2. STATUS REVIEW & THREAT ANALYSIS

KNOWN LOCATIONS *	observed # adults	main threats
Umpala river canyon Meseta Barrigones	398	- agricultural activities on the meseta - soil erosion & presence of goats
Umpala river canyon Meseta Lipial	213	- soil erosion & presence of goats
Umpala river canyon Meseta Grande	143	- soil erosion & presence of goats
Umpala river canyon River slopes	303	- agricultural and human-development activities (housing) nearby
Umpala river canyon Qda. Chinavega	120	- agricultural and human-development activities (housing) nearby
Quebrada del monte canyon	~1000	- agricultural and human-development activities (housing) nearby = low impact
Chicamocha river canyon	46	- agricultural and human-development activities (housing) nearby
Guaca river canyon	110	- agricultural and human-development activities (housing) nearby

* definition of a location (IUCN 2001):
The term 'location' defines a geographically or ecologically distinct area in which a single threatening event can rapidly affect all individuals of the taxon present. The size of the location depends on the area covered by the threatening event and may include part of one or many subpopulations. Where a taxon is affected by more than one threatening event, location should be defined by considering the most serious plausible threat.

Chicamocha canyon views : main region of distribution of *Z. encephalartoides*

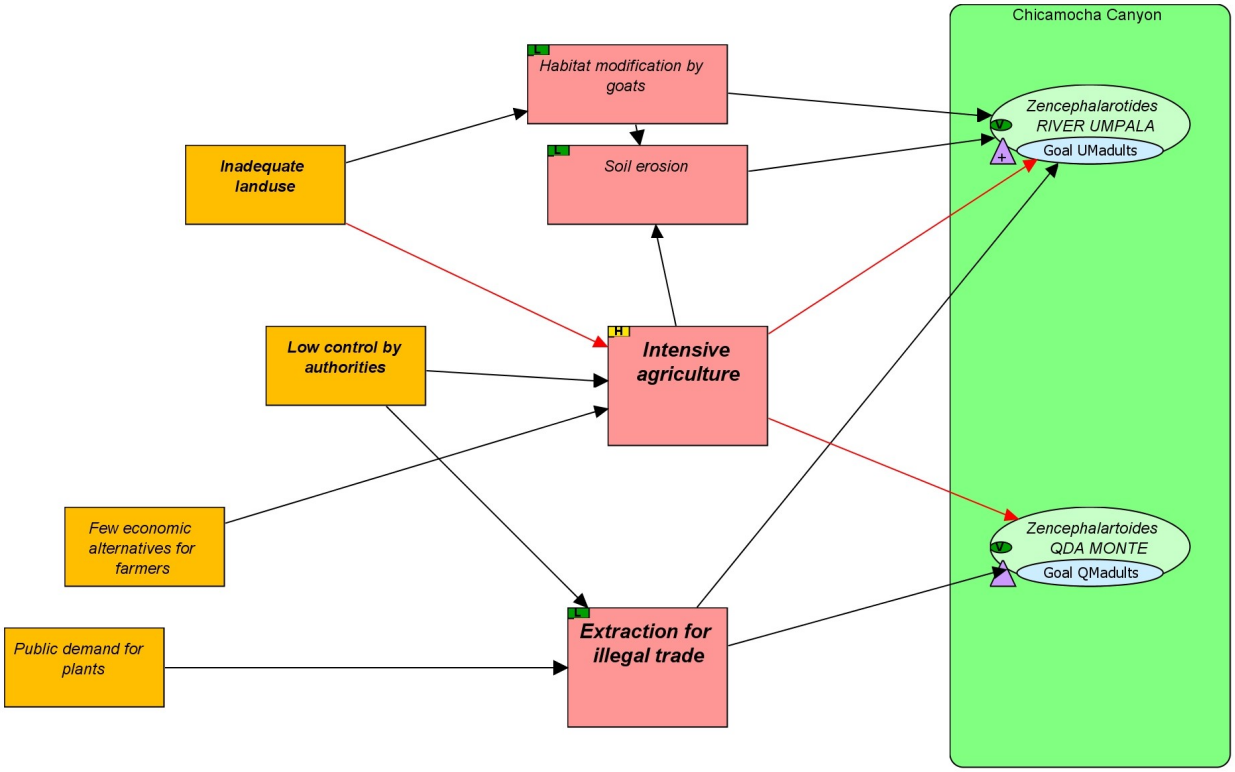
PRIORITIZATION OF DIRECT THREATS *	rationale
i. Intensive agriculture	Many locations for the species lie within private land owned by small traditional farmers. The habitat is highly modified by agricultural activites such as: small-scale crops (tobacco, corn, citrics and other fruits), the construction of trails. *Z. encephalartoides* plants are directly removed from the soil to clear soil for these agricultural activities.
ii. Extraction for illegal trade	Illegal extraction for commercializing the plants have been reported by scientists and local environmental authorities, although the impact of this practice might be restricted to the more accessible sites were the species is present (near the main road that communicates the cities of Bucaramanga and Bogota). The amount of plants removed for illegal trade is unknown.
iii. Soil erosion in habitat	The habitat for the species is characterized by xerophytic vegetation, and when the habitat is modified by agriculture or changes in the dynamics of the biological community soil erosion might accelerate. Habitat area for *Z. encephalartoides* is lost at fast rates by this soil erosion.
iv. Habitat modification by goats	Goats use extensively all the habitat where the species is present, and they can introduce sever modifications to the composition and dynamics of the plant community. Goats seem not to affect directly *Z. encephalartoides* plants, but habitat modification could indirectly affect individuals by modifying the conditions in the ecosystem.

* Importance of the threats was evaluated using a conceptual model (CMP 2007[+]), and according to three criteria: scope, severity, irreversibility

***Zamia encephalartoides* in habitat in sites near intensive agriculture**

+ CMP -Conservation Measures Partnership 2007. *Open standards for the practice of conservation; version 2.0.* CMP, USA.

Conceptual model to explore threats for the conservation of populations
(following CMP 2007)



Habitat degradation in populations of *Zamia encephalartoides*
note the removal of vegetation in preparation for cropping activities in the left image

3. IUCN CATEGORIZATION

PREVIOUS CATEGORIZATIONS	IUCN category	criteria
Colombian Red list assessment 2005	CRITICALLY ENDANGERED	B1ab(iii)
IUCN Red list assessment 2009	VULNERABLE	A2acd;C1

POPULATIONS TRENDS	rationale
POPULATION REDUCTION	Some reduction in the number of individuals for the species is suspected, but there is no reliable information previous to this study on total population size to infer the magnitude of this reduction.
POPULATION DECLINE	It is likely that the species has experienced a *continuing decline* in population size and maybe area of occupancy because of habitat loss and degradation and some illegal extraction of plants.
SEVERE FRAGMENTATION	There are only four known subpopulations (sensu IUCN) known for the species, all of them small (less than 1500 individuals) and all of them in remnant habitat surrounded by a matrix dominated by agricultural and human-settlement lad uses.

RELEVANT PARAMETER (this study)	criteria	potential category
TOTAL POPULATION SIZE = 2000-2500 adults	C1	VU
POPULATION REDUCTION suspected	A2 a c d	VU
AREA OF OCCUPANCY =77 km^2 < 500 km^2	B2 a b	EN
SEVERE FRAGMENTATION		
POPULATION DECLINE suspected		

Proposed IUCN categorization:	criteria
ENDANGERED	B2 a b

4. CONSERVATION PLAN

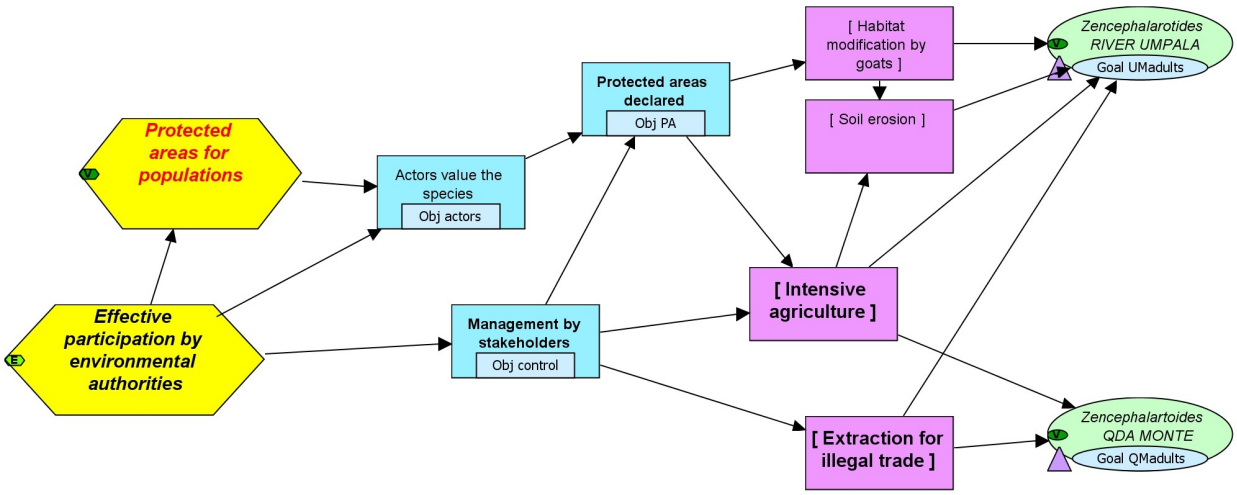
STAKEHOLDERS	rationale
Local environmental authorities	These officers can declare areas for resource management and conservation to guarantee habitat and population viability in the long-term and are in charge of implementing control measures to avoid illegal trade of plants and perpetuate conservation strategies. The regional Botanical Garden "Eloy Valenzuela" that coordinates actions for endangered plant species is managed by the CAR (Colombian local environmental authority) CDMB (Corporacion para la Defensa de la Meseta de Bucaramanga).
Researchers and Conservationists	Researchers from several academic institutions (Botanical Garden Bucaramanga, Colombian Universities UIS & UdeA, Montgomery Botanical Center USA) and other people interested in Cycad conservation (IUCN Cycad Specialist Group, Botanical Garden in Medellin) are interested in generate useful information to support conservation strategies for the species.
Small farmers (land owners)	All locations for the species lie within private land owned by small local farmers, without their support for establishing conservation areas and controlling threats for the species its conservation will not be feasible.
Local human communities	Support of the local communities in other farms and small towns is critical to ensure the viability of conservation strategies in the region.

VISION	MAIN GOALS
In the Chicamocha valley region *Zamia encephalartoides* represents a charismatic resource of its ecosystems and all known populations are managed to ensure their long-term viability in their remaining habitats.	Goal I. All populations of *Z. encephalartoides* have been identified and population abundance and distribution are well estimated in the Chicamocha valley region by 2014.
	Goal II. The largest populations of *Z. encephalartoides (*>500 individuals) are preserved within protected areas to halt potential population reduction and programs to monitor their viability are in place by 2015.
	Goal III. Human communities and farmers near *Z. encephalartoides* locations know about the importance of the species and have effective incentives to preserve the populations by 2020.

OBJECTIVES	OBJECTIVE TARGETS	ACTIONS *
Obj 1. Identify all populations in the Chicamocha valley region.	1.1. The Chicamocha valley region has been well explored and all populations have been identified by 2012.	1.1.1. Extensive field surveys to locate populations performed by local environmental authorities and researchers.
Obj 2. Evaluate population status for all known locations.	2.1. Demographic studies to estimate population abundance and distribution (baseline for monitoring) have bee performed in all known locations by 2014.	2.1.1. Demographic studies to estimate population abundance and distribution performed by researchers.
Obj 3. Declare protected areas for the largest populations (>500 individuals).	3.1. Protected areas with appropriate management plans have been established in the largest populations by 2015.	3.1.1. Legal processes coordinated by environmental authorities for declaring protected areas. 3.1.2. Workshops wit relevant stakeholders to design management plans for protected areas.
Obj 4. Define with all stakeholders adequate strategies to prevent population reduction by habitat degradation and other threats.	4.1. Conservation strategies agreed among relevant stakeholders for avoiding population reduction have been defined by 2016.	4.1.1. Workshops with relevant stakeholders to discuss conservation strategies proposed by environmental authorities and researchers.
Obj 5. Develop effective incentives for stakeholders for species conservation.	5.1. Legal incentives to ensure effective management of protected areas and other conservation strategies are implemented by 2018.	5.1.1. Workshops with relevant stakeholders to identify incentives for conservation and discuss their implementation. 5.1.2. Legal actions to implement conservation incentives for stakeholders coordinated by environmental authorities.
Obj 6. Implement monitoring programs to evaluate population viability in the long-term and inform conservation strategies.	6.1. Monitoring programs to evaluate population biology parameters yearly and explore population dynamics are running from 2015 through 2025.	6.1.1. Demographic census every year performed by researchers and data analysis that generate useful recommendations for stakeholders.

* Objectives, targets and actions were defined using a conceptual model for a situational analysis to evaluate strategies and propose result chains (following CMP 2007)

Results chain to define objectives, targets, actions for the conservation of populations
(following CMP 2007[+])



***Zamia encephalartoides* in habitat growing near human settlements**

+ CMP -Conservation Measures Partnership 2007. *Open standards for the practice of conservation; version 2.0.* CMP, USA.