CLIMATE CHANGE: ITS IMPACT ON THE SPATIAL DISTRIBUTION OF PUYA GLOMERIFERA

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RESUMEN

Se evaluó la distribución espacial de *Puya glomerifera* MezySodiro (Achupalla) relacionada con los efectos posibles del Cambio Climático, empleando los parámetros climatológicos de temperatura y precipitación en la Reserva Ecológica Cotacachi Cayapas. Su número de individuos fue estimado mediante parcelas de 10x10 m^2, en cinco diferentes pisos climáticos que van desde los 2000 a 4000 m.s.n.m. considerando 500 m entre cada uno. Se levantó una base de datos climáticos desde los Anuarios Meteorológicos del INAMHI de estaciones situadas en las cercanías del lugar de estudio con el objetivo de estimar las variaciones mensuales como multianuales de los parámetros estudiados para los años 1990 – 2012. Se obtuvo como resultado que *Puya glomerifera* vive entre los 3000 – 3500 m.s.n.m. De forma similar y para el mismo período, se realizaron cálculos con la base de datos provista del programa EdGCM para evaluar su distribución temporal. En el período dado, los resultados del programa sobrevaloran los datos reales medidos en las estaciones, siendo necesario introducir el cálculo de un factor de ajuste, cuyo valor para la precipitación fue de 0,79 y para la temperatura, 0,63. Utilizando el mismo programa, se realizó una simulación de la variación de la temperatura y precipitación para dos períodos a largo plazo 2013-2040, y 2013-2070, 28 y 58 años, respectivamente, proyectados para el Ecuador y luego aplicados a la región de estudio con los factores de ajuste ya obtenidos. Con un modelo de envoltura climática desarrollado por los autores, se evaluó el comportamiento de la *Puya glomerifera* frente a los resultados de las variaciones de los parámetros climáticos investigados para los dos periodos futuros, obteniéndose que la planta tendría que adaptarse al piso climático situado entre los 3500 y 4000 m.s.n.m. Se proponen estrategias para la conservación de esta especie considerando cuatro factores: educación, investigación, monitoreo y gobernanza.

Palabras clave: *Puya glomerifera* MezySodiro (Achupalla), Cambio Climático, Modelo de Envoltura Climática (CEM).

ABSTRACT

The effects of climate change on the spatial distribution of *Puya glomerifera* Mez y Sodiro have been evaluated using the climatic parameters of precipitation and temperature in the Cotacachi-Cayapas Ecological Reserve. The number of individual plants was estimated by parcels of 10x10 m2 in five different climatic altitudes that range from 2000 to 4000 meters above sea level, with 500 m intervals.

A climate database was created from the Meteorological Yearbooks INAMHI, of stations located near the study site, in order to estimate both monthly and multi-year variations of the two studied parameters, for the years 1990 – 2012. The results show that plant lives at an altitude level that ranges between 3000 - 3500 meters above sea level.

Similarly, for the same period, calculations were made with the database provided by the EdGCM software to evaluate its distribution. In the given period, the results overestimated the reals measured at the stations, therefore it was necessary to introduce the calculation of an adjustment factor, whose value for the precipitation was 0.79 and for the temperature, 0.63. Using the same software, a simulation of the variation of temperature and precipitation was done for two long-term periods 2013-2040, and 2013-2070, 28 and 58 years, respectively, projected for Ecuador and then applied to the region of study with the adjustment factors already obtained. With a Climatic Envelope Model (CEM) developed by the authors, the behaviour of *Puya glomerifera* is evaluated, taking into account the results of the variations of the two climatic parameters investigated. The findings show that the plant would have to adapt to the climatic altitude located between 3500 and 4000 meters above sea level for both investigated periods. Strategies for the conservation of the plant are proposed considering four factors: education, research, monitoring and governance.

Keywords: *Puya glomerifera* Mez y Sodiro (Achupalla), Climate Change, Climate Enveloped Model (CEM)

INTRODUCTION

Nowadays, the planet Earth is seeing big changes in climate, precipitation and temperatures, which are outside their normal ranges (Montealegre y Pabón, 2000). The present study area is not the exception, since precipitation increases with height to a certain altitude (Dumas, 2007), and nowadays the tendency to increase is greater. Over the Cotacachi region, the average temperature is around 18 °C, varying monthly with values in December that can reach up to 14°C, while in August 28 °C (Brito y Michelena, 2014). Several effects of climate change on the region plants have been widely documented, it is already known that plants have responded to this change in two main ways, migration and adaptation; however, at present the high levels of habitat fragmentation could affect future migrations.

The plasticity or capacity for adaptation of the species is limited and large changes in the balance of resources can cause changes in the composition of them (Alvarado, Foroughbakhch, Jurado, y Rocha, 2002). The investigated specie is on an endemic nature existing in the area, *Puya glomerifera*, MezySodiro, known in the country as Achupalla. The ethnobotanical use of the plant is wide as, for instance, the powder found on the back of the leaves is used to cure burns. The region inhabitants use this specie as fodder, by cutting the leaves, using the basal part or trunk. It is also used as fence; some communities have sown this plant around their lands, using it as boundary and wall. In dry seasons, when pasture for cattle and guinea pigs is scarce, the plant is used as food for the Andean bears (Japón, 2009).

It is predicted that climatic fluctuations, such as the variation of the patterns of precipitation or temperature, could cause the extinction of the descendants of these species in near future, due to its inability to find an adequate climate in a sufficient time period. Understanding their population dynamics and modeling their future are necessary measures to avoid the species' extinction (Grau, Gomez, y Araóz, 2010).

The impact of climate change on the potential distribution of four Mediterranean pine species – *Pinus brutia* Ten., *Pinus halepensis* Mill., *Pinus pinaster* Aiton, and *Pinus pinea* L. – was studied by the Climate Envelope Model (CEM) to examine whether these species are suitable for ornamental uses without frost protection in the Carpathian Basin (Bede-Fazekas, Horváth, Kocsis, 2014).

Palacios (2016) analysed the incidence of the variation of the temperature and precipitation over the stages of the Andean grains chain value in the North of Ecuador, applying the manual for the analysis of capacity and climate vulnerability (CVCA) to know which of the stages of the value chain had been most affected by particular climate threats. The objective of that investigation was to find possible adaptation strategies to climate change for the actors living in the region.

Almendáriz (2018) conducted a research to know the behaviour of anurans against climate change. The used climate envelope model states that the three investigated species: *Gastrotheca riobambae*, *Pristimantis curtipes* and *Gastrotheca orophylax*, will adapt to the changes in temperature and precipitation, simply changing the altitudinal floor and ranges in terms of precipitation and temperature.

The main aim of the present investigation is to evaluate the reaction of *Puya glomerifera* MezySodiro in the new potential climatic context estimated in our calculations considering the global IPPC A1B scenario for a medium and long term.

MATERIALS AND METHODS

The present research used both field and documentary work, applying direct, observational, comparative, analytical and statistical methods, starting with the characterization of the climatic situation within the reserve and buffer zones, using 23-year historical data of the closest meteorological stations and within the established heights (Table 1).

During the investigation in the field, through visual observation and asking the residents of the area, it was concluded that *Puya glomerifera* does not exist within the climatic altitudes of 2000, 2500, and 4000 m a.s.l. The plant was identified by observation in the field only within the range of 3000 to 3500 m a.s.l. Five parcels of 10x10 m^2 were established for the quantification of the number of individuals. Three parcels were made within the reserve at 3119, 3259, 3450 m a.s.l, and two in the buffer zone at 3381 and 3460 m a.s.l. The number of plants was determined by manual counting.

Table 1. Location of the parcel and number of individuals within them

Parcel	X (m)	Y (m)	Height (m a.s.l)	N° of plants	Location
1	790275	33639	3379	75	First data collection (Buffer zone)-Fence
2	794392	34948	3459	26	Second data collection (Buffer zone) -Dispersed in the parcel
3	794696	32484	3123	80	Third data collection (RECC- Ruta Sagrada)-Dispersed in the parcel
4	795432	33568	3259	90	Fourth data collection (RECC-Sendero Las Orquídeas)-Dispersed in the parcel
5	795162	33945	3448	95	Fifth data collection (RECC- Las Orquídeas Trail)-Dispersed in the parcel

Figure 1 shows the location of the Cotacachi-Cayapas Ecological Reserve and its buffer zone. The X, Y coordinates are given in meters, under the location WGS84, Z17UTM

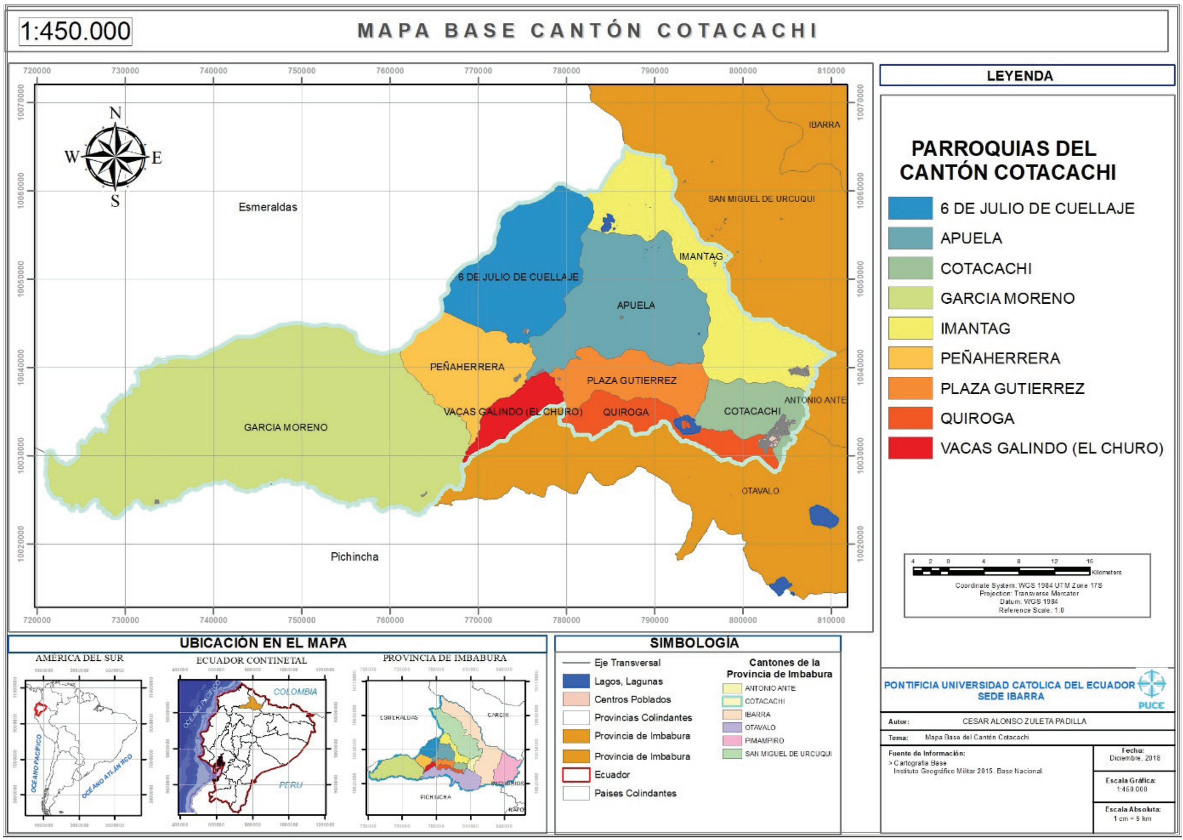

Figure 1. Map of the Cotacachi Canton, where the data collection was carried out.

The meteorological stations were selected according to the following factors: on the one hand, taking into account that they were within the province, on the other hand, the altitude of the stations, which must be between 2000-4000 meters above sea level and, as a third factor, the stations that are closest to the Cotacachi-Cayapas Ecological Reserve.

The chosen rainfall stations were in total 12; as shown in table 2.

Table 2. Used Precipitation Stations

Code	Name	Latitude	Length	Height (m a.s.l)	Station type
M0318	Apuela-Intag	0 ° 21 ‘ 18 “ N	78 ° 30 ‹ 49” W	1620	PV
M0021	Atuntaqui	0 ° 21 ‘ 13 “ N	78 ° 13 ‘ 39” W	2200	PV
M0107	Cahuasqui-FAO	0 ° 31 ‘ 5 “ N	78 ° 12 ‘ 40” W	2335	OC
M0317	Cotacachi-HDA. Esthercita	0 ° 18 ‘ 18 “ N	78 ° 16 ‘ 07” W	2410	PV
M0325	Garcia Moreno	0 ° 14 ‘ 5 “ N	78 ° 37 ‘ 38” W	1950	PV
M0909	Gualsaqui	0 ° 19 ‘ 15 “ N	78 ° 24 ‘ 30” W	2710	PV
M0328	HDA. La Maria -Anexas (Leticia)	0 ° 20 ‘ 54 “ N	78 ° 16 ‘ 11” W	2600	PV
M0001	Inguincho	0 ° 15 ‘ 30 “ N	78 ° 24 ‘ 03” W	3140	OC
M0312	Pablo Arenas	0 ° 30 ‘ 8 “ N	78 ° 11 ‘ 34” W	2340	PV
M0324	San Francisco de Sigsipamba	0 ° 17 ‘ 53 “ N	77 ° 54 ‘ 42” W	2230	PV
M0326	Selva Alegre-Imbabura	0 ° 14 ‘ 47 “ N	78 ° 34 ‘ 37” W	1800	PV
M0321	Topo-Imbabura (Angla)	0 ° 12 ‘ 41 “ N	78 ° 09 ‘ 58” W	2860	PV

Source: Anuarios Meteorológicos INAMHI. Station type: PV (Pluviometric), OC (Ordinary Climatic).

The chosen temperature stations were in total 4 (See Table 3)

Table 3. Used Temperature Stations

Code	Name	Latitude	Length	Height (m a.s.l)	Station type
M0107	Cahuasqui-FAO	0 ° 31 ‘ 05 “ N	78 ° 12 ‘ 40 “ W	2335	OC
M0001	Inguincho	0 ° 15 ‘ 30 “ N	78 ° 24 ‘ 03 “ W	3140	OC
M0105	Otavalo	0 ° 14 ‘ 36 “ N	78 ° 15 ‘ 00” W	2550	PC
M1094	Tomalón-Tabacundo	0 ° 02 ‘ 00 “ N	78 ° 14 ‘ 00” W	2790	AP

Source: Anuarios Meteorológicos INAMHI. Station type: OC (Ordinary Climatic), PC (Principal Climatic), AP (Agrometeorological).

Through the database, it was possible to determine the parameters (precipitation and temperature) under which the plant can live. After this, the data collected from the meteorological stations were analysed and compared with the EdGCM software global data developed by the Columbia University.

The climatic variables that regulate the meteorological behavior at global level are in constant alteration. For this type of analysis, a global climate model (EdGCM) is used, which can be adopted to represent various climatological variables such as solar radiation, air surface temperature, precipitation, evaporation, etc.; analyzing their behavior and the changes that each element presents in a certain period of time (The Basic Guide to EdGCM, 2009).

The EdGCM is an integrated software, designed to simplify process of creation, run, analysis and reporting in simulations of global climate modeling. The software divides the atmosphere into a three-dimensional cell system. The model extends globally in the horizontal axe containing 7776 cells in the atmospheric network, where each horizontal column corresponds to 8° latitude by 10° of length, and has nine vertical layers and two on the surface (Estrada, 2009). Running the climate model involves solving a series of complex physical equations for each grid in the cell, and the simulation of a single year involves calculations of billions of operations (EdGCM (2009).

For the territory of Ecuador, four squares were used, located between: Latitude: 4 ° and -4 °, Length: -75 ° and -85 both for precipitation (See Fig. 2) and for temperature (See Fig. 3). In these cases, the software considers all the country's regions, being necessary to make an approximation, applying an adjustment factor to compare its results with the calculated in the present investigation, cf. Figure 1 and Figure 2.

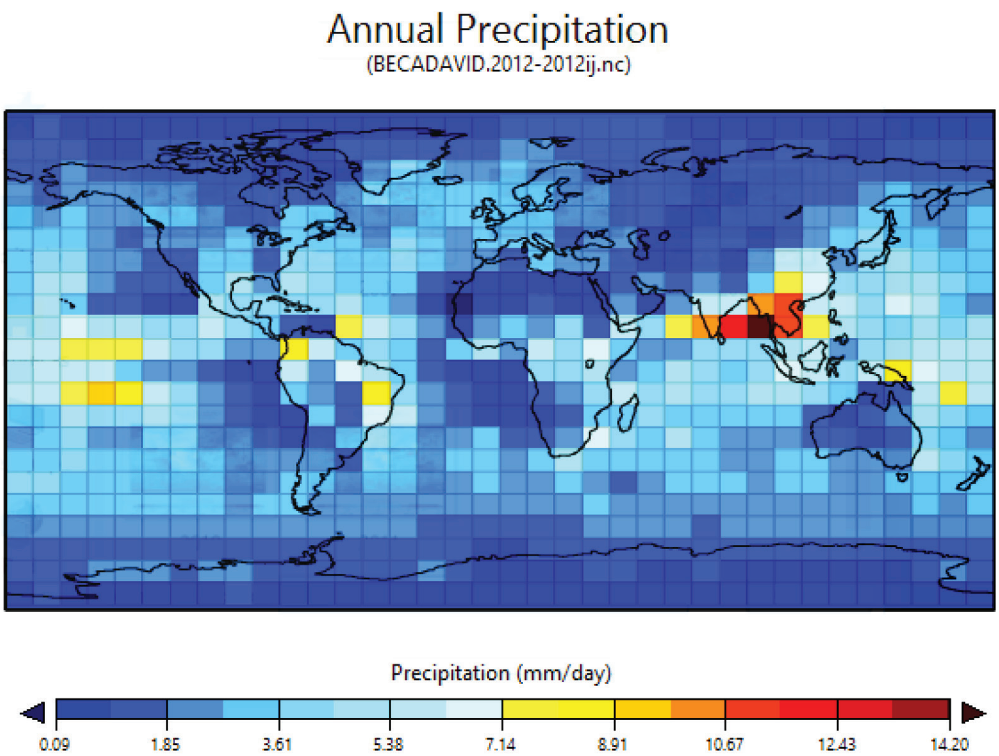

Figure 2. Global Precipitation for 2012
Source: Software EdGCM Version 3.2 (2009). Prepared by: Geomara Almeida

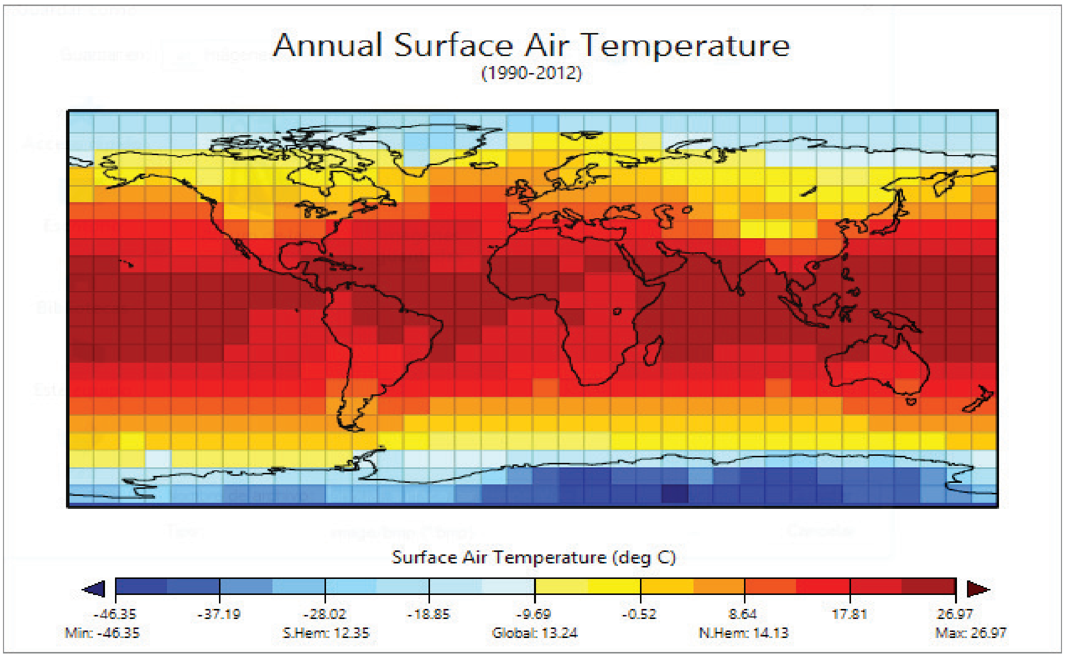

Figure 3. Global Multiannual Temperature for the 1990 – 2012 period
Source: Software EdGCM Version 3.2 (2009). Prepared by: Geomara Almeida

The hydro-thermodynamic equations system, closing hypothesis

In the atmospheric models, we usually work with spatial and temporal averages in which the Reynolds averaging rules, and the equations related to the hydro-thermodynamic system of the atmosphere in the fixed Descartes coordinate system to the Earth are applied, increased with the moisture transport equation related to each phase and with the pollutant transport equation. It is notable that the equations are fulfilled in both time and space (at all times and in each place) (Baranka et al. 2013).

This type of programs applying the Navier–Stokes equation system:

$$\frac{du}{dt} = \frac{\partial u}{\partial t} + u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} + w\frac{\partial u}{\partial z} = -\frac{1}{\rho}\frac{\partial p}{\partial x} + fv - lw + F_{sx}$$

$$\frac{dv}{dt} = \frac{\partial v}{\partial t} + u\frac{\partial v}{\partial x} + v\frac{\partial v}{\partial y} + w\frac{\partial v}{\partial z} = -\frac{1}{\rho}\frac{\partial p}{\partial y} - fu + F_{sy}$$

$$\frac{dw}{dt} = \frac{\partial w}{\partial t} + u\frac{\partial w}{\partial x} + v\frac{\partial w}{\partial y} + w\frac{\partial w}{\partial z} = -\frac{1}{\rho}\frac{\partial p}{\partial z} + g - lu + F_{sz}$$

Where:
$u,v,w,$ = the components of speed in x,y,z

p = the system pressure

ρ = the density

g = the gravity

f= the Coriolis parameter

l= factor for calculating the Coriolis parameter

Fsx, Fsy, Fsz = the friction force in x,y,z

We used a climate envelope model (CEM) that models species distribution ("niche models") and uses mathematical rules or functions to describe the associations between the presence of species and environmental conditions. The climate envelope models delineate areas of climatic suitability for the species of plants or animals of interest, by means of the correlation of the occurrences of georeferenced species (presences and absences) with climatic conditions observed in the sites of occurrence (Illoldi y Escalante, 2008).

RESULTS AND DISCUSSION

In the present investigation, the multiannual distribution of two climatological elements, the precipitation and the temperature have been studied in order to search an eventual relationship between the variation of these two parameters and the development of *Puya glomerifera*, MezySodiro.

Bede-Fazekas (2017) investigated the vulnerability of natural habitats to future climate change for Hungary applying regional climate models as ALADIN-Climate and RegionalCM with negative results on the most climate sensitive forested habitat types of Hungary, however, the author experienced positive predicted responses for grassland types.

Commonly in sciences, such Meteorology, Climatology, Hydrology, where data series are used, the applied methods are stochastics, in many cases making averages. The values represented in the figures show the average monthly values of each station calculated from the available 23-year data, a single value was obtained, the so-called multi-year average of the station. With each of these values per station, the multi-annual average was calculated for the analysed period.

Precipitation

Figure 4 shows the average multiannual precipitation relationship between the meteorological stations and the global software EdGCM for 1990 – 2012.

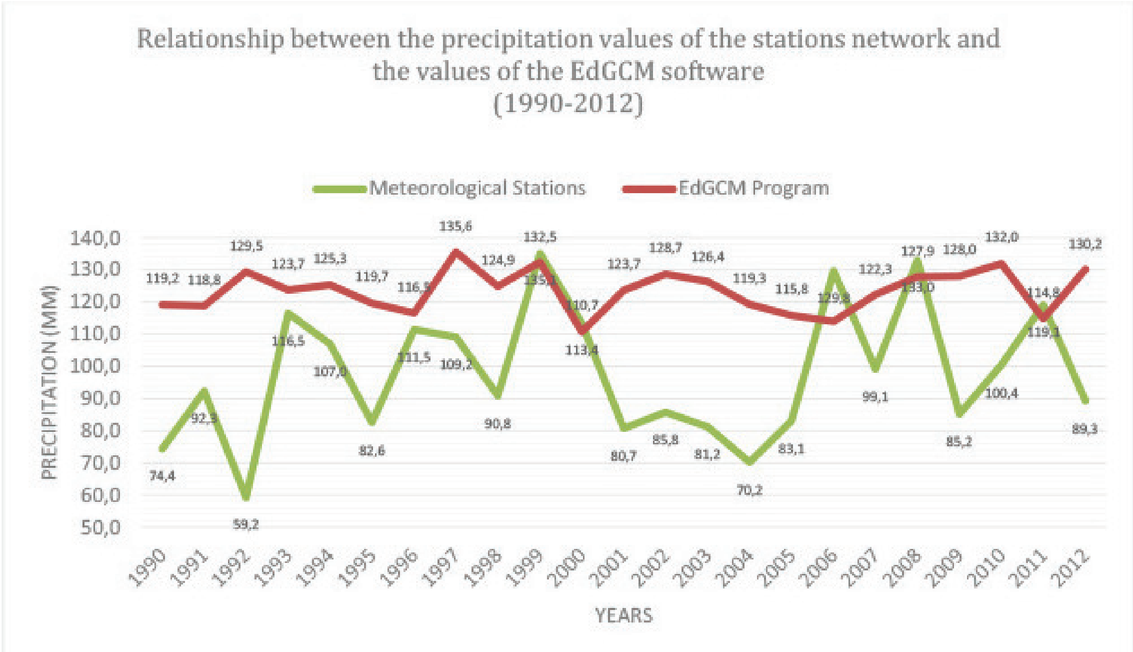

Figure 4. Relationship between the precipitation values of the stations network and the EdGCM program

As shown in Figure 4, the global software EdGCM overestimate the precipitation values of the meteorological stations, while the stations' values oscillate in lower intervals, being necessary to introduce an adjustment factor to obtain an approximation of the two curves.

The program shows the results of the four grids analysed for the territory of Ecuador, whereas the present investigation is only meant for a specified territory, that's the reason why these differences were found.

Adjustment factor of the EdGCM software towards the precipitation real values

Comparing the obtained results from the calculations based on the precipitation data of the selected stations with those of the EdGCM database, the results of the software are overvalued.

To find an approximate relationship between the distributions of the curves, it was necessary to calculate an adjustment factor for the obtained values, applying an analysis determining the anomalies corresponding to each year related to the total average. In the case of precipitation, the adjustment factor is equal to 0,79.

Figure 5 shows the precipitation relationship between the stations and the program values applying the adjustment factor for the period 1990-2012 to analyse the behaviour of the plant at the present.

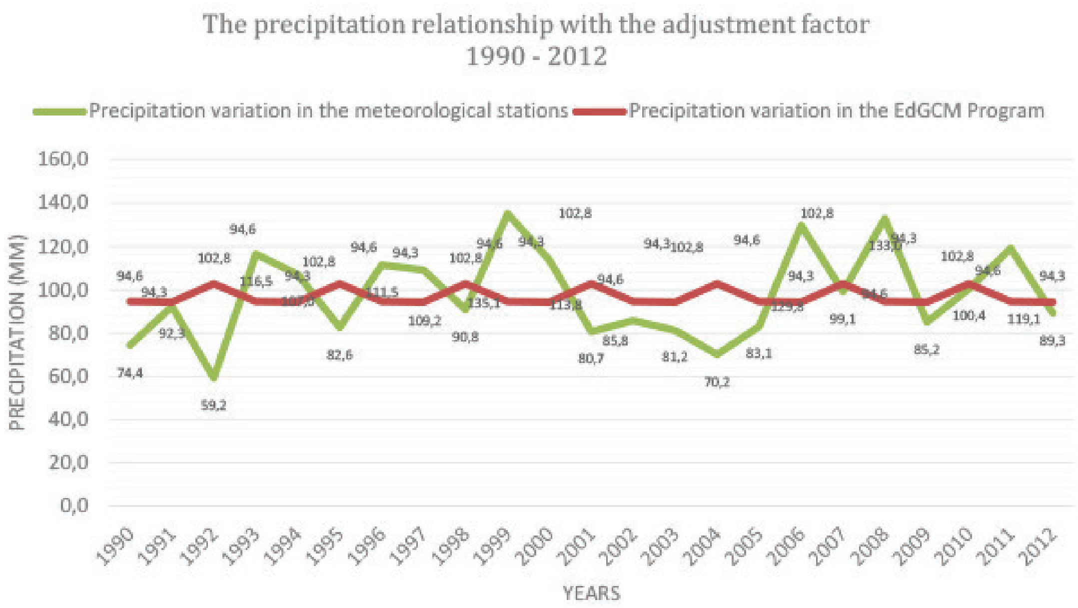

Figure 5. Precipitation relationship with the adjustment factor 1990 - 2012

The adjustment factor for the precipitation has a margin of error 20,8% in the calculation of the total anomalies. If we consider the variation of the precipitation of the meteorological stations the total sum of the anomalies rounds off 5%; while for the calculation of the EdGCM program by 2%, that is, the anomalies are very stable in both cases. It indicates that the calculated approximation is correct.
Figures 6 and 7 present the variation of the multi-year average precipitation in the future made by the global program EdGCM from 2013 to 2040 and from 2040 to 2070, respectively:

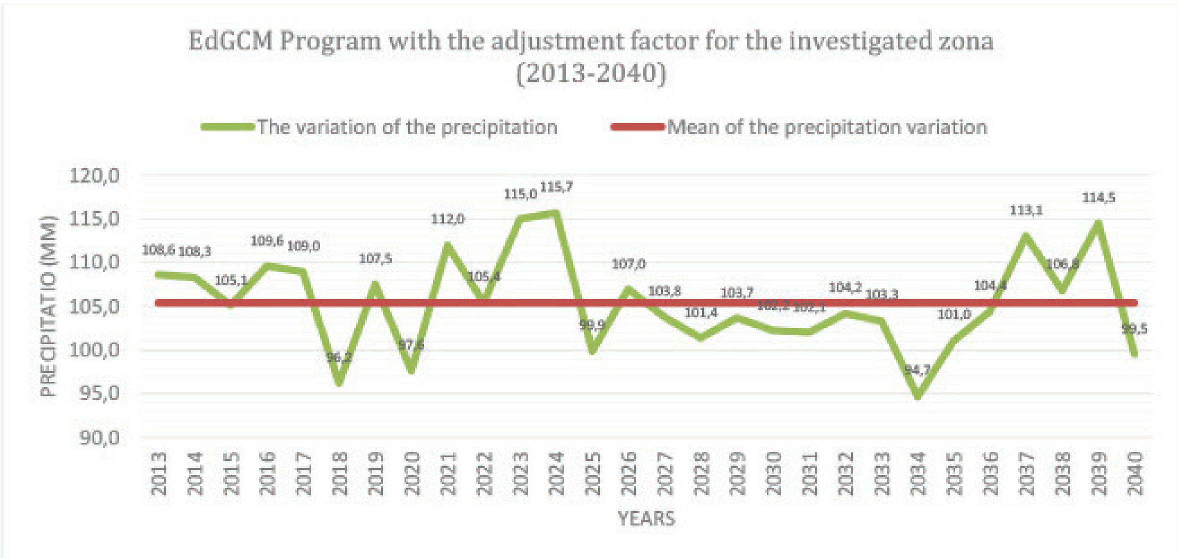

Figure 6. EdGCM Program with the adjustment factor for the investigated zona (2013-2040)

According to the global program EdGCM, in the period 2013 – 2040, the average of precipitation would be around 105,4 mm. From the Figure 4, it can be concluded that there are several anomalies with great values in the year 2024 with 10,3 mm and in the year 2034 with -10,7 mm.

That differences are correct from the precipitation temporal and special distribution.

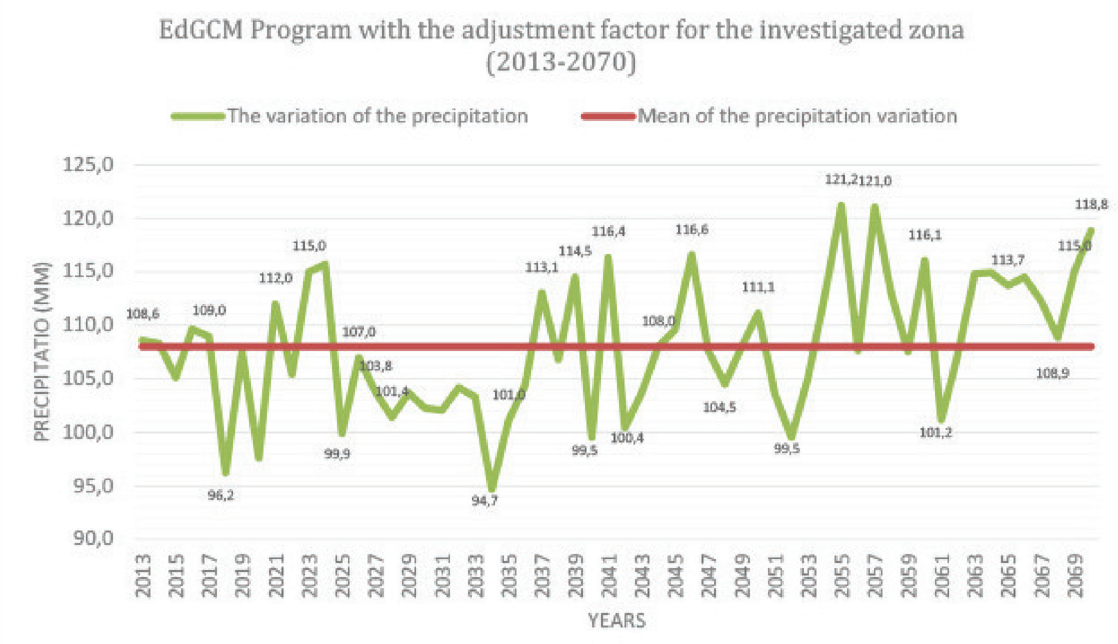

Figure 7. EdGCM Program with the adjustment factor for the investigated zona (2013-2070)

For the period from 2013 – 2070, the average rainfall would be 108 mm. Along the 58 years investigated, several anomalies oscillate around the average, with a range of 26,5 mm, expecting a minimum in 2034 and maximums in 2055 and 2057.

That differences are correct from the precipitation temporal and special distribution.

Temperature

Figure 8 shows the multi-annual variation of the temperature for the meteorological stations and global programme EdGCM, for the period 1990-2012.

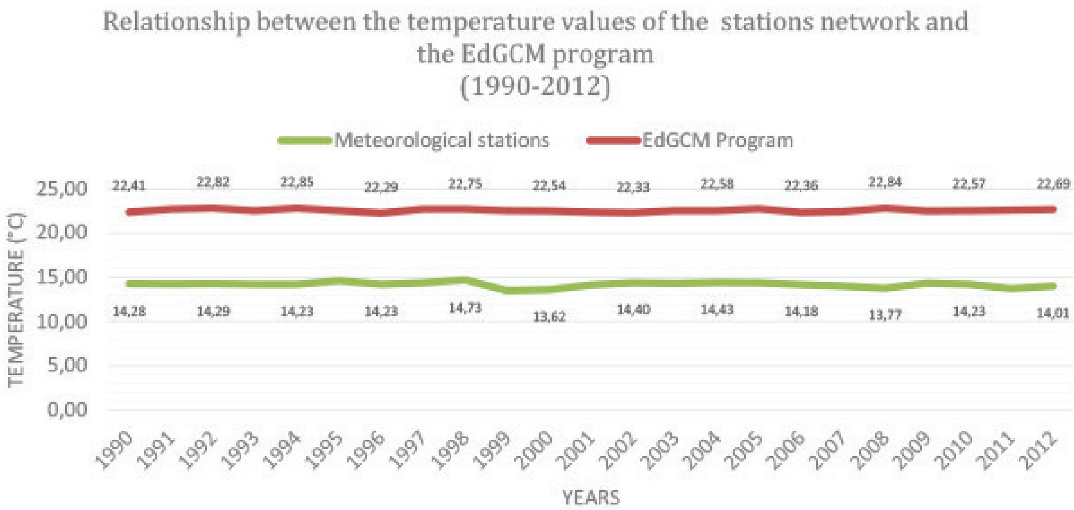

Figure 8. Relationship between the temperature values of the stations network and the EdGCM program (1990-2012)

The graph indicates that the trend for the two cases is similar, having to apply an error factor to find the necessary adjustment between the two data series.

Adjustment factor of the EdGCM software towards the temperature real calculations

For the temperature, it was also necessary to calculate an adjustment factor for the obtained values, applying an analysis determining the anomalies corresponding to each year related to the total average. In this case, the adjustment factor is equal to 0,63.

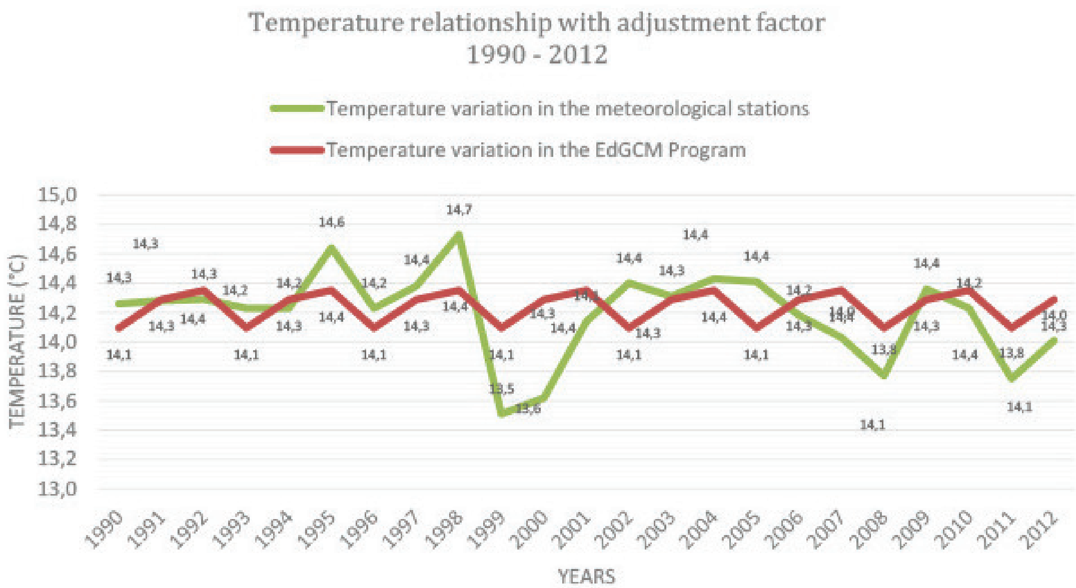

Figure 9. Temperature relationship with adjustment factor 1990 - 2012

Figure 9 shows the temperature relationship between the stations and the program values applying the adjustment factor for the period 1990-2012.

After carrying out an analysis of the adjustment factor for temperature, we found that there is a higher error than in the case of precipitation with a percentage of 34.65% in the calculation of the anomalies. For the meteorological stations, the total sum of the anomalies has an error around 5%. For the calculation of the EdGCM software, the total sum of the anomalies rounds up to an error of 7%, which means that the anomalies move within very acceptable, stable ranges.

Figures 10 and 11 show the variation of the multi-year average of the temperatures in the future, made by the global software EdGCM from 2013 to 2040 and from 2040 to 2070, respectively, applying the adjustment factor.

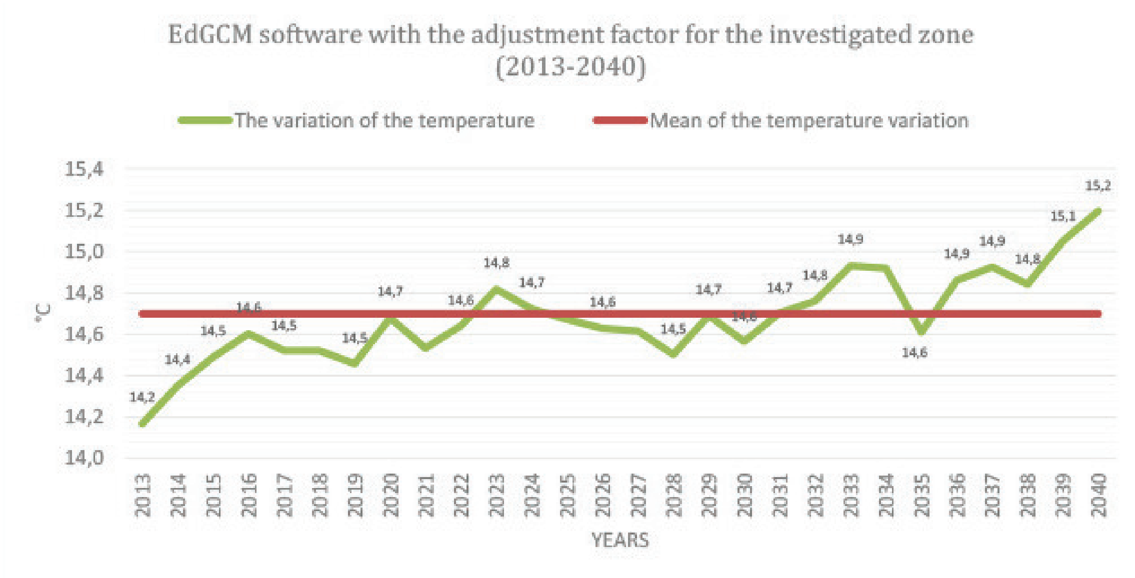

Figure 10. EdGCM software with the adjustment factor for the investigated zone (2013-2040)

From Figure 10, it can be concluded that the temperature will increase by 1 °C from the year 2013 to the year 2040.

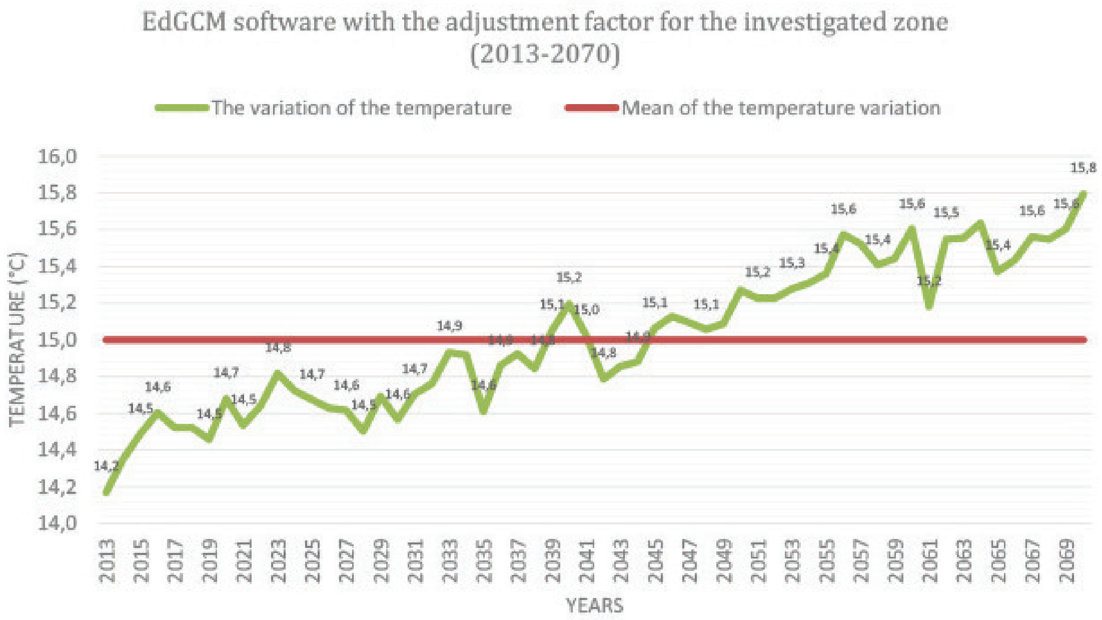

Figure 11. EdGCM software with the adjustment factor for the investigated zone (2013-2070)

As we can see in the Figure 11, the temperature will increase by 1,6 °C from 2013 to 2070.

Climate Envelope Model (CEM)

The climatic envelope model was developed based on height, precipitation and temperature parameters. The height levels range oscillate from 2.000 to 4.000 height above sea level with intervals of 500 m. At each level, ranges of both precipitation and temperature were established. The precipitation multiannual mean ranges from 55 mm to 150 mm. For the temperature, the ranges considered were from 10 °C to 20 °C.

Next, the conditions proposed in the flow diagram are detailed.

Table 4. The survival conditions for *Puya glomerifera.*

	Condition 1	Condition 2	Condition 3	Condition 4
Height (m)	2000-2500	2500-3000	3000-3500	3500-4000
Mean of Precipitation (mm)	< 55 - 70	70-85	85 -100	100 - >125
Temperature (°C)	18 – 17,5	17,5 - 16	16 -13,5	14,1 -14,97

Based on the calculations for the future, it can be observed that precipitation and temperature increase. In order to understand the relationship between the increase of the two parameters and the development of the plant, a future condition was established for each of the variables through the results of the EdGCM database. The first three conditions are current. The following algorithm shows the form of the interdependent distribution of the mentioned parameters, it is of logical order.

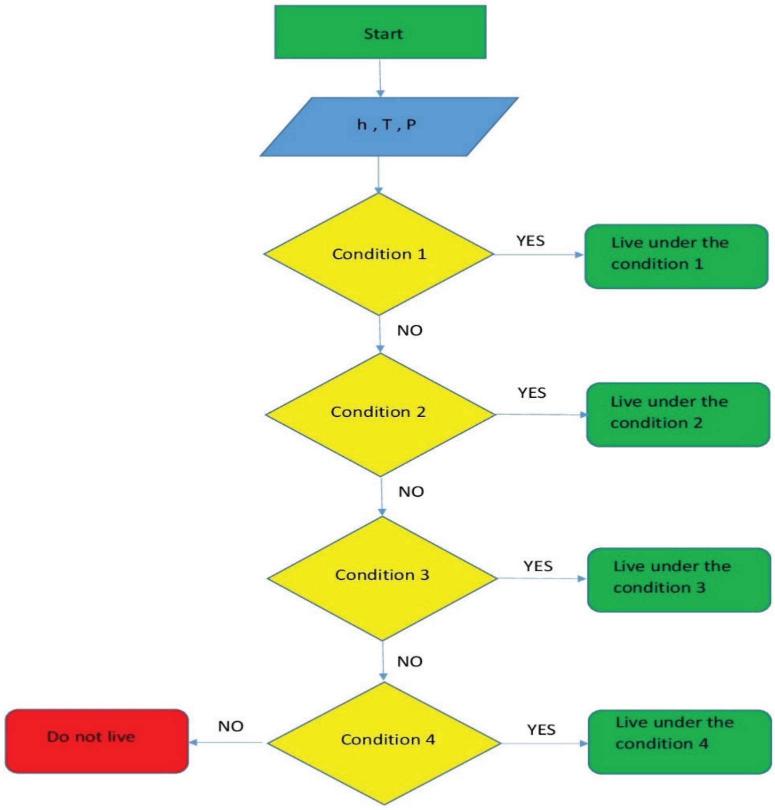

Figure 12. Algorithm and its process

Algorithm takes into account three variables namely, height, precipitation and temperature. According to the living conditions of the plant, four height levels were chosen with the ranges of the precipitation and temperature parameters for each of them. If the conditions in which the plant can live are in accordance with the given height, the program closes satisfactorily. If the established condition does not meet at the analysed height, it automatically goes to the next condition until it reaches the last level and if at this level it does not meet the established parameters the plant does not live.

In the analyses for the future, the multiannual average of rainfall and temperature averages is taken into account according to the EdGCM database. With the obtained data in the periods of 28 and 58 years, the increase in precipitation and temperature is considerable and indicates that the only ideal condition for the life of the plant is 4 years.

Algorithm can be applied for the entire given region, considering that a database was created during the course of the investigation, and projections can be generated for the future.

Some strategies for the conservation of the species:

Encourage scientific research and generation of information regarding climate scenarios, monitoring of climatic variables, analysis of current and future potential impacts, vulnerability and capacity assessment, as well as the identification of appropriate technologies, including knowledge and ancestral knowledge of the indigenous communities and local people, in order to guarantee food security.

It is necessary to find adaptation solutions based on ecosystem services to mitigate the risks, and threats of natural disasters caused by climate change on biodiversity and local populations.

CONCLUSIONS

An approximation of the precipitation and temperature for the period 1990-2012 was made for two series of data, one of them corresponding to the data of the meteorological stations situated in the surroundings of the Ecological Reserve Cotacachi – Cayapas, the other one was the EdGCM database. After the application of an adjustment value, the distribution of the series gives a good approximation. Using the EdGCM database, two projections were prepared, one for the period 2013-2040 and the other for 2013-2070 with varied results. The flow diagram used in the Climate Envelope Model states that the Puya glomerifera Mez y Sodiro would adapt to the changes in temperature and precipitation variables, however the species would change altitudinal floor and ranges in terms of precipitation and temperature.

It is recommended that the Ministry of the Environment follow the strategies suggested in this project for the plant species to adapt to future climate variation. Encourage investigations with this type of studies including different types of plants, or focus more on the morphological change of the plant with respect to climate change. In addition, continue with the monitoring of the plant, and if losses are evident, continue with a reforestation strategy.

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