Temperate forests and climate change in Mexico: from modelling to adaptation strategies

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Abstract
At present there is no doubt that climate change is affecting the structure, function and the geographic distribution of temperate ecosystems at regional and global scales; however in Mexico information about impacts of climate change on temperate forest ecosystems are scarce. The present chapter presents two studies of the effect of climate change on distribution of species of pines and oaks, and the change in functional groups composition of temperate forests ecosystems in Mexico; and, finally we resume a experience on identifying adaptation measures in a local forestry sector to climate change with three participatory workshops with key actors in forestry at state level. We realized a projection for the year 2050 that included two scenarios, a severe and a conservative one of how climate change would impact spatial distribution to 17 species of oaks and 17 species of pines at national level. Results of this study showed that the effect of alterations in temperature and precipitation modeled under both climate-change scenarios will reduce the current ranges of geographic distribution of almost all species of oaks and pines. Responses of these species to the different scenarios of climate change are predicted to be species-specific and related to each species affinity. The most affected species under the severe and conservative climate change scenarios will be *P. rudis*, *P. chihuahuana, P. culminicola, P.oocarpa, Q. acutifolia, Q. crispipilis*, and *Q. peduncularis.* On the other hand we show an analysis of the possible responses of functional groups was based on the construction of an ensemble of eight general circulation models with four scenarios of global emissions, and a Japanese model of regional high resolution (20 x 20 km) for Oaxaca state at South of Mexico. The ensemble of climate change scenarios suggested that by 2050 the temperature of the region will increase between 1.5 and 2.5°C, and rainfall will vary between +5 and -10% on current annual total precipitation. The sensibility analysis pointed that for the climate change scenario in 2050 genera as *Abies* and *Pinus* restricted their distribution area, in contrast, gender or drought-tolerant shrubs are likely to increase their geographic

distribution. In another regional study in Tlaxcala (central Mexico) climate change scenarios projected a condition of drier and warmer (lower soil moisture) climate during the spring, thus the risk of forest fires would increase. Besides, losses of climate change of cover forest are another hazard in the state like illegal logging and land use change. It is estimated that by 2080 there will be only about 40% of the actual forest area in Tlaxcala by illegal logging and harvesting practices. Therefore, climate change will accelerate the forests loss in the state and in two or three decades will be very little remaining to preserve. As a result of a series of stakeholders in Tlaxcala we identified adaptation strategies that we grouped under three headings: reforestation, forest conservation and production.

1. Introduction

Some of the key climatic variables that stress structure and functioning and geographic distribution of forest ecosystems are those related to changes in precipitation, temperature, potential evapotranspiration, and increased frequency of fires and storms. Notwithstanding that the structure, composition of the species, and the functionality of the present ecosystems are the result of a series of physical conditions that have made possible its existence (Maslin 2004, Parmesan 2006), it is unknown how will the species adapt to an increase in temperatures between 2 and 5°C in the next 100 years; as well as to all the variations of precipitation between +20 y –20% in average for the planet (Sholze et al. 2006). It is also unknown if the adaptation mechanisms of plants will occur at the same speed than the climate would (IPCC 2007), since future changes will be different in magnitude than the preceding from the last 10,000 years (IPCC 2007). These changes in climate can have present and future impacts on the distribution, diversity of the species, the structure and and function of these ecosystems. Thus, measurement of present and future ecosystems modification, due to the climatic changes, is imperative (Malcolm 1998, Locatelli 2006). The effects on present tendencies on climate in the temperate forests of the world are manifested with greater differential mortality frequency of individuals among species, the presence of plagues and the decrease of productivity in forests (Rebetez & Dobbertin 2004, Mueller et al. 2005).

Climate change can have an influence on the species distribution. The changes on structure, function, species composition and geographic distribution could have profound implications for traditional livelihood, industry, biodiversity, soil and water resources, and hence, agricultural productivity. Moreover, these climate change induced effects would aggravate the existing stresses due to non-climate factors, such as land use changes and the unsustainable exploitation of natural resources.

In Mexico, pine and oak forests occupy 32, 330, 508 ha which represents 17% of the country. These are the richest ecosystems in Mexico with some 7000 plant species, from which about 150 species are pines and 170 are oaks; these represent over 50% of all known pine and oak species. Some species in these temperate forests produce timber of high commercial value in the forestry market. The rate of deforestation (0.5% annually) and illegal logging (21 million m^3 $year^{-1}$) are high. Mexico is the 11^{th} largest emitters of CO_2 from deforestation and contributes 1.6% of global emissions, mainly from its temperate and tropical forests (12.9 and 54.1 Pg C $year^{-1}$, respectively). Temperate ecosystems of Mexico have received a strong influence of anthropogenic activities because they have an important population concentration (51% of the national population), with high growth rate (3%) (Villers & López

1995). The subsequent pressures upon the resources are manifested on the land use change and on the high deforestation rate. Forestal areas have a loss around 500,000 ha yearly (Palacio et al. 2000). Likewise, climate change could influence in the number and distribution of species: for example, likely 1,806 species will be affected in the coniferous forest, 1,309 species in the tropical forests, 1,345 species in the xerophilous scrubland, and 1,060 species in the mesophilous mountainous forests (Arriaga & Gómez 2004). Probably, forestal ecosystems deterioration in Mexico could be greater than the impact of climatic change itself (Gómez et al. 2006). That is why, it is necessary to begin studies on the effect of global warming at a key species scale and its spatial distribution at a national scale, in order to identify its vulnerability to climate change, as it was pointed out by the Fourth National Communication to the Framework Convention on Climate Change (Semarnat 2009).

This chapter is an opportunity to integrate information about the impact of climate change on the species distribution of temperate forests in two spatial and temporal scales; and propose guidelines to help the assisted adaptation process of temperate forests to climate change and decrease the environmental deterioration, both synergistic problematic in temperate forests of Mexico. Therefore, the objectives of this contribution were: i) a description of the simulation results and experiences of species distribution models with coupled models and regionalized country scale species of oaks and pines of wide and narrow geographic distribution; ii) an identification of thresholds identifying functional groups of plants in the mountain range of the Sierra Norte of Oaxaca using regional climate simulations; and iii) finally we present our experience, through government initiatives to identify adaptation measures to climate change in three participatory workshops with key players in forestry in the state of Tlaxcala.

2. Modelling potential distribution of pines and oaks

A diversity of models has been generated to identify the vulnerability of biodiversity to climate change (Stocker 2004; Thuiller et al. 2004; Visser 2004; Araujo et al. 2005; Ohlemuller et al. 2006). Most of these studies use general circulation models (GCM) to generate climate change scenarios through physical functions of energy feedback in climatic change components, as well as greenhouse effects emissions scenarios. However, GCM need to be regionalized or downscaled to get better predict changing values of temperature and rainfall at a higher spatial resolution. Also, models of global and national distribution of species, including climate models and ecological niche are methodological approaches to understand the effect of climate change on vegetation. An example of this is the simulation model GARP (Genetic Algoritm for Rule Set Prediction), based on the ecological requirements of species and logistics regressions to simulate potential distributions of those species (Stockwell & Peters 1999). An exercise was made to simulate the potential effect of climatic change upon the spatial distribution of 17 pine species and 17 oak species in temperate forests of Mexico using the GARP model (Gómez & Arriaga 2007). A projection for the year 2050 was made including two views of how climate would change: a severe one and a conservative one. Through a statistical downscaling process, average temperature change was obtained and the precipitation for the MCG HADCM2 under SRES A1 (severe) scenarios and B2 (conservative).

Results with the conservative emissions scenario suggest that the spatial distribution of pines decreases less than the severe scenario and once again the decrease of the area is variable (0.1 to 50%). Pine species more sensitive to and total precipitacion changes were in its geographic distribution, were *P. oocarpa*, *P. chihuahuana* and *P. rudis*. On the other hand, moderate sensitive pine species were *P. patula*, *P. durangensis*, *P. arizonica*, *P. teocote*, *P. ayacahuite*, and *P. culminicola*. It is worth noting that *P. cembroides* is one of the most tolerant species to climatic change, it will only loose 8% of its present distribution (Figure 1). Oaks seem to have less probability of modifying its geographic distribution, because they only decreases between 6 and 27% under the most conservative scenario (Figure 1). Species with high vulnerability to modify its geographic distribution are *Q. peduncularis*, and *Q. acutifolia,* while, the rest of the species will change its distribution between 6.8 and 17.7 %. Significant reductions will be present for *Q. castanea and Q. laeta* (Gómez & Arriaga 2007).

Results of this study showed that long-term vegetation changes can be expected in the temperate forests of Mexico as a consequence of climate change. Alteration in temperature and precipitation modeled under both climate-change scenarios will reduce the current ranges of distribution of almost all species of oaks and pines. Results for the more severe scenarios suggested that the effects will depend upon the species and the reduction of distribution levels have shown variations between 0.2 and 64%. The most sensitive species to change based on its future potential distribution by 2050 were *Pinus rudis, P. chihuahuana*, *P. oocarpa*, and *P. culminicola*. On the other hand, *P. patula*, *P. montezumae*, *P. teocote*, *P. ayacahuite*, *P. pseudostrobus*, *P.leiophylla*, *P. arizonica* and *P. herrerae*, shown moderate tolerance to future climate change; while *P. cembroides*, *P. durangensis*, *P. douglasiana*, *P. hartwegii*, and *P. strobiformis* are the most tolerant species to climatic change, thus its geographic distribution did not show significant modifications. In contrast, oak species showed a decrease between 11 and 48% of its present distribution for the year 2050; which suggests lower sensitivity than pine species. Oak with more sensitivity to thermical increase and change in rainfall pattern were *Quercus. crispipilis*, *Q. peduncularis*, and *Q. acutifolia.* On the other hand, *Q. sideroxyla*, *Q. mexicana*, *Q. eduardii*, *Q. castanea*, *Q. laurina*, *Q. rugosa*, *Q. magnoliifolia*, and *Q. crassifolia* resulted to be reasonably tolerant. The most tolerant species were *Q. obtusata*, *Q. durifolia*, *Q. segoviensis*, *Q. elliptica*, *Q. scytophylla*, and *Q. laeta* (Gómez and Arriaga 2007).

The overall results of this study suggests that species with more geographic distribution range does not have less vulnerability to climatic change, because the geographic distribution change of species seems to be related to climatic similarities of the specie itself. For example, pine species with more vulnerability were the ones found in semi-cold and semi-humid climates; areas or habitats were climate will considerable change with climatic change. Thus, species like *P. rudis*, *P. chihuahuaza, P. culminicola*, *Q. peduncularis* and *Q. sideroxyla* that live in these regions will be the ones with greater reductions in its geographic distribution (between 30 and 45%) for the 2050 scenario. Subsequent studies considered that pine species in temperate forests of Mexico, mainly on the regions of central-north, will be more vulnerable to climatic change *P. cembroides* and *P. pseudostrobus* (INE 2009). Together these studies of potential distribution modeling agreed on showing the high level of sensitivity of the species that live in mountainous regions, where temperature changes and reduction of rainfall will affect its development. However, there are still some questions about the environmental tolerance, mainly about climatic envelope that determines the presence of species at a community scale of temperate forests in topographic delimited units enclosed in Mexico.

3. Functional groups and climate change

The term functional group is applied to the group of species that use the same environmental resources class in the same way, this is, those that overlays its ecological niche (Gitay & Noble, 1997; Westoby & Leishman, 1997). In this way, the current climate, being a resource, represents a current climatic tolerance measurement element of species. Such tolerance can be compared with climatic change scenarios to evaluate vulnerability of the functional groups in the future. It is known that under similar climatic parameters in wide geographical levels, the response of the species demonstrate coincide (Retuerto & Carballeira, 2004), because some of the climatic parameters are descriptors of distribution of species (Myklestad & Birks, 1993; Carey *et al.* 1995). However, a more realistic approach requires the application of the regional or local model of the present and future climate so that a suitable policy of conservation for each zone can be applied.

The Sierra Norte of Oaxaca (SNO) has been considered as a priority terrestrial region because of its significance for biodiversity (Dávila et al. 1997; Arriaga et al. 2000). Oaxaca forests take up 8% of its territory (INEGI 2002). This land is considered one of the places with more diversity and endemism for *Pinus* and *Quercus*. Among the more representative species of SNO temperate forests stand out species like *Pinus patula; P. hartwegi, P. ayacahuite* and *P. pseudostrobus,* also *Abies guatemalensis*, *A. Hickelii* and *A. Oaxacana* (Del Castillo et al. 2004). There are also present *Pinus teocote*, *P. rudis, P. leiophylla, P. oocarpa, P. oaxacana, P. montezumae, P. douglasiana, P. lawsonii* and *P. pringlei* (Campos et al. 1992; Farjon 1997).

From a SNO inventory of species, with a total of 149,059 records (CONABIO and CIIDIR) connections between the presence of physiognomic dominant species and climate variations (Díaz et al. 1999; Kahmen & Poschlod 2004) were made in order to identify vulnerability to climate change for several types of vegetation: pine forest, *Abies* oak forest, cloud forests, scrubland, evergreen tropical forest tropical forest, dry tropical forest and dry subtropical forest (Table 1) (INEGI 2001). The determination of the possible responses of functional groups was based on the construction of an ensemble of eight general circulation models with four scenarios of global emissions, and a Japanese model (Mizuta et al. 2006), of regional high resolution (20 x 20 km). The ensemble of climate change scenarios suggests that by 2050 the temperature of the region will increase between 1.5 and 2.5°C, and rainfall will vary between +5 and -10% of the current annual precipitation. Finally, functional groups tolerance was identified by type of vegetation to climate change according to its present climatic preference (Gómez et al. 2008).

By means of arithmetic maps techniques, attribute tables of collect sites georeferenced were constructed with map scales of the total annual rainfall with the software ArcView (ESRI Versión. 3.2), the current habitat preference for each set of species grouped by gender was determined. The results indicated that genera like *Quercus, Pinus and Abies* were distributed among the 1,000 and 2,500 mm annual rainfall.

According to the Japanese model of high resolution (Mizuta et al. 2006), by the year 2050 minimal temperatures will increase more during the months of April and November on the SNO, meaning more warm nights. Rainfall will have significant decrease during winter from November through March (could be less than 100 mm per month), and increasing in July up to 150 mm (Figure 2). According to the climatic change scenarios by increasing minimal temperatures up to 3°C on April and December, genera like *Abies, Pinus*, *Juníperus* and *Quercus* could tolerate this change; because they can live in areas with temperatures up to 14°C. Probably the *Arbutus* in a pine forest and *Abies* and *Amelianchier* in a oak forest could not tolerate this increase on the minimal temperatures, because at the present time they are adapted to –2 a 5°C and from 0 to 6°C, respectively. On the other side, genera of cloud forests, evergreen tropical forest like *Clethra, Dendopanax, Miconia and Percea* have tolerance among minimal temperature of 0 and 14°C. Finally, scrubland genera and dry tropical forest (*Mimosa, Acacia* and *Brahea*) could also tolerate these changes, because they are distributed between –2 and 14°C.

Rainfall change sceneries for the year 2050 show differences among the altitudinal vegetation floors (Figure 2). Rainfall during autumn and winter will decrease in pine forests, while during summer it will be close to the base scenario; in contrast, oak forests will have a rainfall increase during summer. Thus, in the future, SNO pine forests will be dryer and oak forests more humid. This climatic pattern modification suggests that, even though the current temperature has a general increase tendency in the SNO, the differentiation of the anomaly of rainfall could modify the distribution of genera. So, species that require more rainfall levels in pine forests, like *Abies*, could be affected in its geographic distribution.

Regional climatic change scenarios also suggest altitudinal changes on the types of vegetation distribution. The present altitudinal gradient of conifers in the SNO is distributed above the 1,500 m. *Pinus hartwegii* is especially vulnerable to increase in temperature, because it is affected by plagues due to deficiency of low temperatures to eliminate them. *Quercus* is distributed from 150 to 3,500 m in Oaxaca. Species that are distributed at a higher elevation (more than 2700 m) are *Q. crassifolia, Q. laurina,* and *Q. elíptica*, probably these species are the most vulnerable species to climatic change (Gómez et al. 2008).

4. Adaptation capacity building

Once regional scenarios are identified from the assembling of several MCGs, we get close to an identification of future vulnerability of temperate forests of sites geographically enclosed. This way, threats are identified more clearly and adaptation strategies can be generated. However, the real capacity of auto-adaptation in these communities will depend on the no climatic threat magnitude, such as the type of management of forests and land use change. That is why, under the foster of national initiatives a capacity building exercise began with human societies that own, administrate and live in forests on the central region of Mexico. The project Generation Capacity for Adaptation to Climate Change supported by UNDP was to develop case studies to test methodologies, schemes of work disciplines and institutions, and information communication strategies that result in proposals to reduce vulnerability in temperate forest in Tlaxcala, Mexico (Magaña & Neri 2006). The project objective was identifying key actors of the forest sector to understand the condition of vulnerability to climate variability. In this study we work to determine the feasibility of the proposed adaptation strategies, their cost and their effectiveness, so that the methodology could be extended to other regions.

4.1 The forestal sector in the State of Tlaxcala

Tlaxcala State in the central region of Mexico has a surface of 399, 000 ha, from which 16% are forests, 8% are pastures, 74% are cultivable lands, and 1% human settlements. Tlaxcala is one of the states with more erosion index due to high deforestation rates, fire and land use change (Semarnat, 2002). Wood and non-timber products are extracted from Terrenate-Tlaxo municipalities on the North of the State, municipalities like Nanacamilpa and

Calpulalpan, on the West, and the protected natural areas of la Malinche South of the state have problems with clandestine logging (Gobierno del Estado de Tlaxcala 2004). From 1936 to 2000 more than half of the forestal cover has been lost. Under this analysis framework, notwithstanding that silviculture vulnerability points out towards climate, human activities represent the greater threat for the integrity of forests in the area. That is why; non climatic factors have to be considered in an adaptation model in the medium and long time. Climate changes scenarios projected in Tlaxcala drier and warmer condition (lower soil moisture) more frequent in the spring, so the risk of forest fires significantly increases the rate of loss of forest cover. Unless conditions change in the state of Tlaxcala, it is estimated that by 2080 there will be only about 40% of the present area. Therefore, climate change will accelerate forests loss in the state and in two or three decades will be very little remaining to preserve.

4.2 Adaptation Strategies

Through three participative workshops together with key actors and individual surveys measures of adaptation were identified to climatic change through the opinion of local forest producers and managers (Ecology Department, municipalities and SEMARNAT delegations) (Figure 3). Likewise, the feasibility of such measurements in a medium and long term was identified, as its eventual incorporation in the government level strategy. For this study, we applied the Political Framework: APF (UNEP 2004) for the design and execution of the projects to reduce the vulnerability to climate change. Key actors are of extreme importance through the five political adaptation stages marked by APF: 1. Definition and application sphere, 2. Evaluate present vulnerability, 3. Characterize future conditions, 4. Develop adaptation strategies, and 5. Continue with adaptation.

The three participative workshops were held under the monthly session's framework of the Forestal State Council, organization that congregates opinions from agricultural, silvicultural, private and communitarian forests owners, several environmental states institutions and academic representatives related with the study of forestal production and the conservation of state forests (Figure 3). These key factors discussed and prioritized adaptation measurements based on the problematic on climatic change, environmental degradation, and wrong management of forestal resources that they were ready to implement. Measurements of adaptation arrived at by consensus by the different key actors were: conservation, restoration and silvicultural, all of them in a sustainable process framework of forests. Likewise, three application areas at a municipality scale for measurements of adaptation were identified in terms of its benefits, negative impacts, regions, social groups with opportunities, and technical and economic impacts.

a) *Adaptation strategies: Conservation*

Due to the historical deforestation rate in the state, one of the main actions that need to be taken is the conservation of the remaining forest area through different public politic instruments. To this date, there are some federal and state programs that promote environmental services such as the Program for Payment for Hydrological and Environmental Services (PPHES) and the Program for the Environmental Market Services Development of Carbon Capture Derivative of the Biodiversity and the Development of Agroforestry Systems (CONAFOR 2009), that allows conservation of forestal areas in surfaces as in connectivity. Promotion programs state that the owners and land forestal owners are compensated for their services, and environmental services users have to pay them directly or indirectly. Other federal programs are Project of Clean Development Mechanism (CDM) that promotes the National Environmental Secretary (Semarnat). The beneficiaries of these programs are the owners and the owners of forests, academic groups, silvicultural, municipal authorities and communities.

The positive impact of these programs in climatic terms, will be reflected in a greater connectivity between forest surfaces that still are in good conservation in a horizontal and in altitudinal way. This will allow the migration of pine and oak species that will guarantee the permanency of the majority of these species. Likewise, it could help to improve the quality of life (education, health) and the diversity of non-timber products (mushrooms, ecotourism, medicinal plants). All of this promotes the capacity of self-management and it represents an option for creating regional projects sponsored by PPHES, or by international organisms and private businesses independent from federal support.

The feasibility of this measure is high because there are public political instruments that will allow the success of the implementation and monitoring of the conservation strategies. In this case, Development State Plan of Tlaxcala State 2005 – 2010 establishes actions to integrate the regeneration and conservation of forests with the production and planting of young trees. To achieve this success, there is another program for management and fire control for the protected natural areas that allow preserving water and soil. In the same way, there are programs for recovering high erosion areas in the state, conservation, protection and restoration of the forestal mass land of forests and water (Gobierno del Estado de Tlaxcala 2004). These plans and programs have as a final objective, to increase the forestal area for its conservation and management.

b) Adaptation measurement: ecological restoration

An alternative to increase the forestal surface in Tlaxcala is ecological restoration of these ecosystems. The objective of this measurement is to reduce the erosion of the soil, to help the recharge of water and recuperate the biological diversity of arboreal species. Once again, there are public political instruments that guarantee the implementation and monitoring of this adaptation. For example, there is a fiscal stimulus such as the productive reconversion, Temporal Work Program, water capture and reforestation, and the reforestation program in micro basins and the Integral Program for Forestal Resources are just some examples that promote indirectly climatic change adaptation. Mexican Official Rules that can establish mitigation measurements to climatic change, represent an area of opportunity where institutions like INIFAP (Institute of Research on Forest and Agriculture and Livestock) have already started research on genetic optimization processes of species and studies of aptitude for existing varieties under the climatic change scenarios.

c) Adaptation measurements: sustainable forest management

One of the main mitigation and adaptation measurements to climatic change that have been proposed is the sustainable forest management; through the implementation of conservation and carbon capture projects (Cowie et al. 2007). Under the Marrakesh agreements, activities such as afforestation, reforestation, deforestation, forestal management, agricultural management, and grassland management are alternative for mitigating GEI (García-Oliva & Masera, 2004; Cowie et al., 2007). For the implementation of this measurement a State Forestal Program exists for the year 2020, which promotes an increase on the forestal surface under sustainable management. Under this program, the directly beneficiaries are the owners of forests, silvicultural, local authorities and communities. If these measures are established they will be opportunities for the forestal management, the creation of a global state program of natural resources and its link with other productive areas in the State municipalities. Summing up, there are a series of initiatives and programs where a sustainable use of forests can be seen. However, it is still necessary to include the regional climatic change scenarios for Tlaxcala State on the aptitude analysis of the species, stand management use, reforestation programs, erosion decrease practices, and soil recuperation under high erosion, as well as territorial and ecological State level ordination.

5. Conclusions

In Mexico, climatic change is a future threat for the permanency of temperate forests in Mexico, however, the environmental degradation and the inadequate management of forestal resources are the main cause for the loss of these forests in a short term. The increase the increase of temperatures, the variation of rainfall patterns, and change in hydrological balance can have an impact on geographic composition and distribution of species that shelter temperate and temporal forests at different spatial levels. The study at national level suggests that climatic change descriptors will alter the geographic distribution of species; however, the impact was distinctly different between pines and oaks. At a regional scale, a change on the distribution of the species can be detected, on an altitudinal way. The analysis of both spatial resolution scales presented here, suggest that the alteration of climate will change the physiognomic dominant species distribution of temperate forests. However, the factors of local climate, such as geomorphology, orientation, and humid conditions can modify the response of forest communities faced to a climate change. It is important to incorporate the departures of the climate regional models on the behavior studies of the natural species of its own area of importance, for better sustainable use or for the conservation of forest areas in the country.

On the public policy arena at a federal level, it is encouraging to know that there are some attempts to establish adaptation measurements of the forestal sector to climatic change. It is important to point out that measurements proposals have double objective: adaptation to climatic change and environmental degradation reduction, both synergetic problematic in temperate forest of Mexico. This new knowledge, in combination with the ones already obtained from other Mexican scientists, will give bases to generate strategies for sustainable forestal management that will contribute to the reduction of CO_2 carbon emissions and face better the climatic change challenge.

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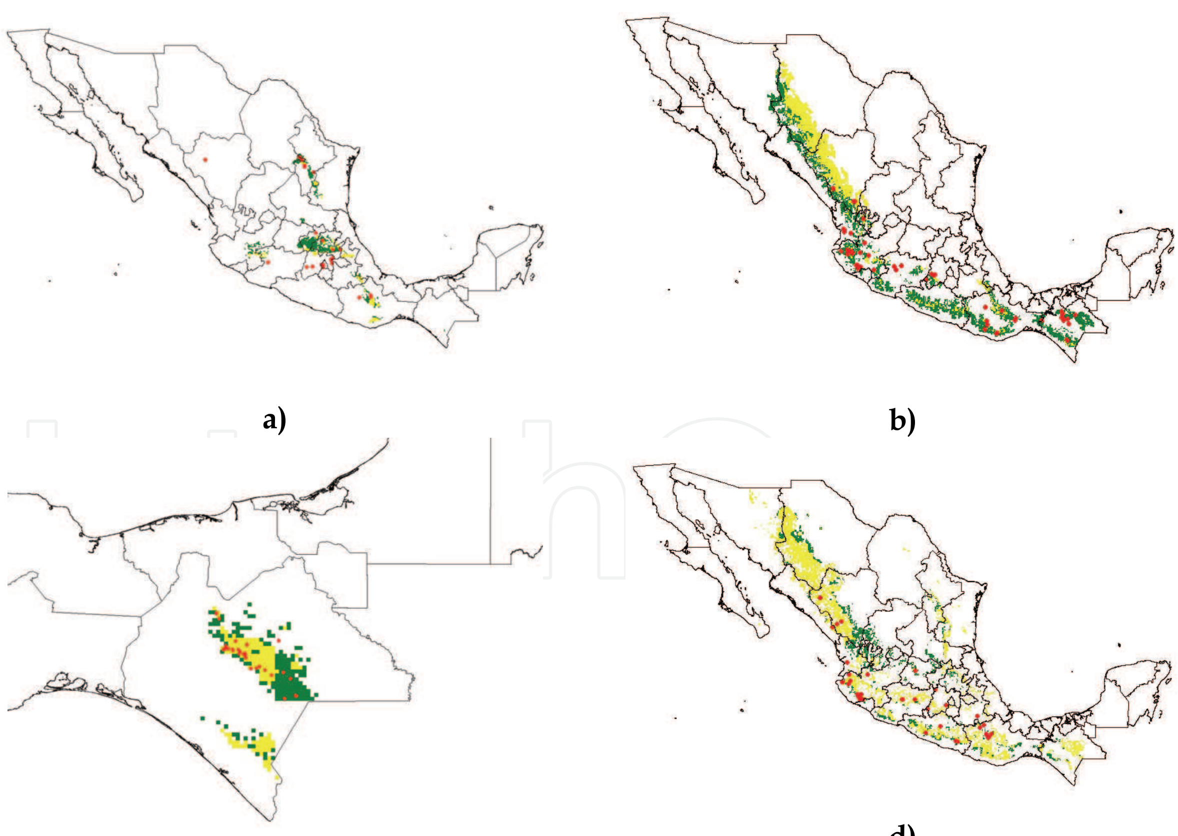


a) b) c) d)

Fig. 1. Potencial distribution of a) *Pinus rudis*, b) *P. oocarpa*, c) *Quercus crispipilis* and, d) *Q. magnolifolia* under severe climate change scenario (yellow). Current distribution (green) and collecting data (red points) are showed.

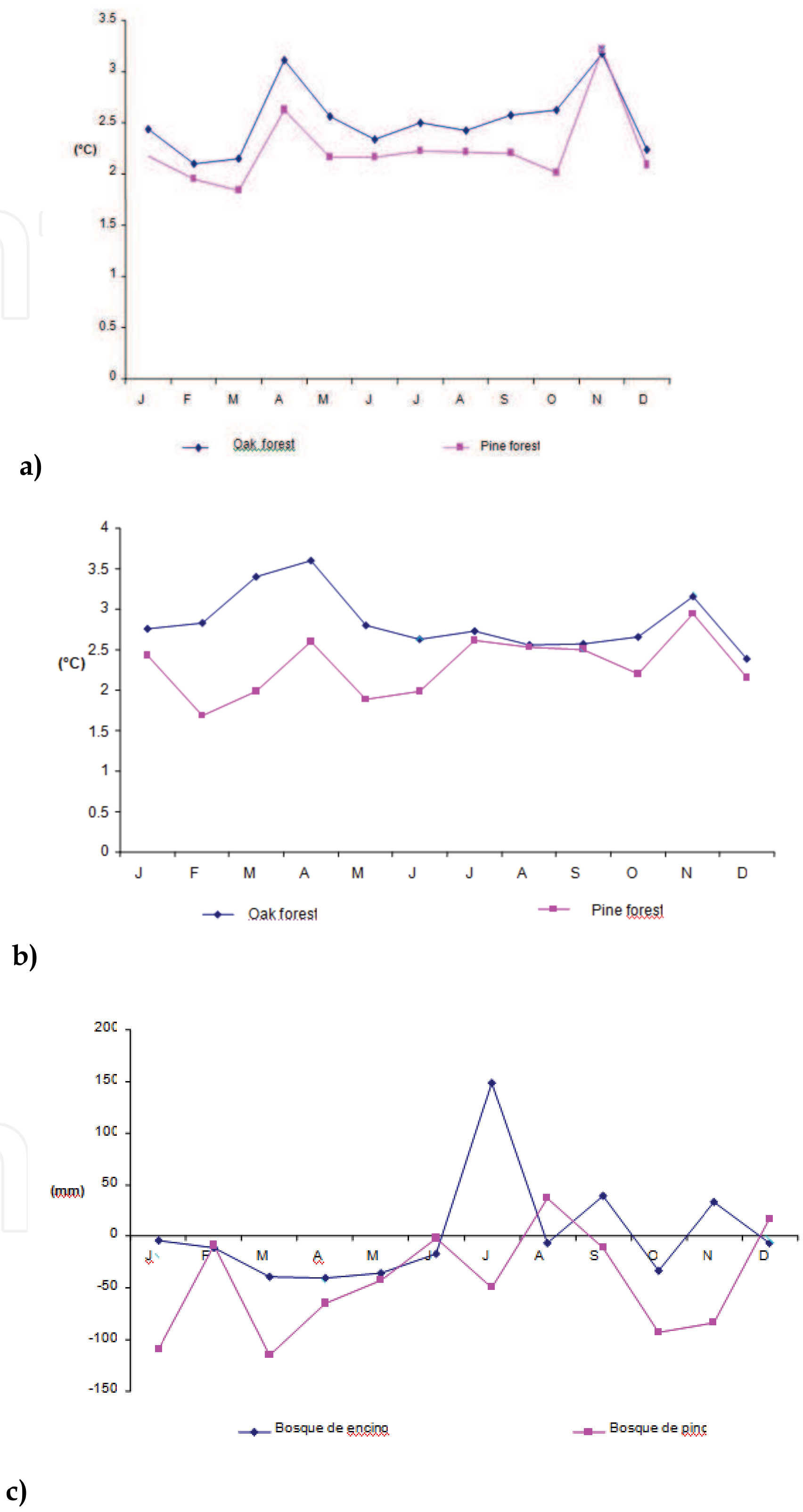
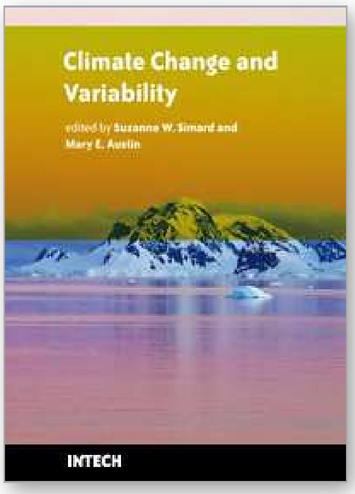


Fig. 2. Climate change scenarios for 2050: a) changes in minimum temperature ; b) changes in maximum temperature and, c) changes in total precipitation in Sierra Norte of Oaxaca, México.

Fig. 3. Participative workshops in Tlaxcala Mexico.

Vegetation type	Physiognomic dominant species	
	Tree species	Brush species
Abies and pinus forest	*Abies hickelii**	*Amelanchier denticulata**
	*Juniperus flaccida**	*Arteostaphylus pungens*
	*Pinus ayacahuite**	*Baccharis heterophylla**
	*Pinus devoniana**	*Bejaria aestuans**
	*Pinus hartwegii**	*Calliandra grandifolia**
	*Pinus oocarpa**	*Gaultheria acuminata**
	*Pinus patula**	*Rhus virens*
	*Pinus teocote**	*Arbutus xalapensis**
	*Quercus crassifolia**	*Comarostaphylis discolor*
	*Quercus elliptica**	*Litsea neesiana**
	*Quercus laeta**	*Roldana sartorio*
Oak forest	*Carpinus caroliniana*	*Comarostaphylis discolor*
	*Quercus elliptica**	*Gaultheria acumina*
	*Quercus laeta**	*Listea glaucescens**
	*Quercus rugosa**	*Lyibua squamulosa*
	*Quercus scytophylla**	*Myrica cerifera*
	*Styrax argenteus**	
Cloud forest	*Clethra sp**	*Calyotranthes schiedeana*
	*Dendropanax populifolius **	*Miconia lonchophylla*
	Ilex discolor	
	Liquidambar styraciflua	
	*Persea americana**	
	*Pinus patula**	
	Podocarpus matudae	
	*Quercus candicans**	
	*Saurauia spp**	
	*Styrax glabrescens**	
	Weinmannia pinnata	

Table 1. Physiognomic dominant species by vegetation types in Sierra Norte of Oaxaca.



Climate Change and Variability
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Climate change is emerging as one of the most important issues of our time, with the potential to cause profound cascading effects on ecosystems and society. However, these effects are poorly understood and our projections for climate change trends and effects have thus far proven to be inaccurate. In this collection of 24 chapters, we present a cross-section of some of the most challenging issues related to oceans, lakes, forests, and agricultural systems under a changing climate. The authors present evidence for changes and variability in climatic and atmospheric conditions, investigate some the impacts that climate change is having on the Earth's ecological and social systems, and provide novel ideas, advances and applications for mitigation and adaptation of our socio-ecological systems to climate change. Difficult questions are asked. What have been some of the impacts of climate change on our natural and managed ecosystems? How do we manage for resilient socio-ecological systems? How do we predict the future? What are relevant climatic change and management scenarios? How can we shape management regimes to increase our adaptive capacity to climate change? These themes are visited across broad spatial and temporal scales, touch on important and relevant ecological patterns and processes, and represent broad geographic regions, from the tropics, to temperate and boreal regions, to the Arctic.

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