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Simulated dynamics of net primary productivity (NPP) for outdoor livestock feeding coefficients driven by climate change scenarios in México

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RESUMEN

En este trabajo se aplicó el concepto de productividad primaria neta (NPP, por sus siglas en inglés) como una forma de estimar la capacidad que tienen los ecosistemas de producir materia seca (DM, por sus siglas en inglés) que puede estar disponible para que el ganado cubra sus requerimientos de forraje. El método permite simular bajo condiciones de cambio climático el impacto posible que sobre la NPP y la materia seca se podrán observar para el país a un horizonte de tiempo dado. El concepto además fue aplicado sobre los coeficientes de agostadero actuales y bajo escenarios de cambio climático, permitiendo observar los posibles cambios en superficie requerida para la alimentación sostenible del ganado. Así, se encontró que en México se tienen valores de la NPP que van desde 0 y hasta 50 000 kgDM/ha/año. La DM, por su parte, se encuentra en el rango que va de 0 hasta 25 000 kgDM/ha/año. Los coeficientes de agostadero para el escenario actual no cambian considerablemente con relación a los presentados por COTECOCA, el organismo oficial encargado de su determinación. Bajo los escenarios de cambio climático se encontró que los estados de Baja California, Baja California Sur, Coahuila, Colima, Jalisco, Nuevo León, Puebla, Querétaro, San Luis Potosí, Sonora, Tamaulipas, Veracruz y Yucatán podrán ser los más impactados por posibles cambios en las condiciones actuales y verán modificados sus coeficientes de agostadero en el futuro. A partir de lo anterior se discuten las implicaciones que se podrán observar y se analizan las alternativas propuestas por el gobierno federal para el sector ganadero del país.

ABSTRACT

In this paper the concept of Net Primary Productivity (NPP) is used as a way to estimate the capacity of the ecosystem to produce dry matter which may be available for livestock to meet the forage requirements. The method allows the simulation of the possible impact on NPP and dry matter (DM), under climate change conditions observable for the country in a given time horizon. The concept was also used for current coefficients of rangeland and under current climate change scenarios, thus allowing to observe possible changes on the required surface for a sustainable cattle nutrition. It was found that México has NPP values ranging from 0 to 50 000 kgDM / ha / year. Dry matter is in the range that goes from 0 to 25 000 kgDM / ha / year.

The coefficients of rangeland for the current scenario do not change significantly compared to those presented by COTECOCA, the official body determining such values. The states that present a greater impact due to current conditions under climate change scenarios were Baja California, Baja California Sur, Coahuila, Colima, Jalisco, Nuevo León, Puebla, Querétaro, San Luis Potosí, Sonora, Tamaulipas, Veracruz and Yucatán; this group will also have changes in its coefficients of rangeland in the future. Considering all of the above we discuss the implications that can be observed and we analyze the alternatives proposed by the federal government for the country's livestock sector.

Keywords: dry matter, rangeland, cattle nutrition, scenarios, sustainability.

1. Introduction

Between 14 and 22% of global greenhouse gases (CO_2 equivalent) come from livestock activity (FAO, 2006); specifically it is accountable for 9% of the CO_2 emissions (mainly due to deforestation), 37% of methane emissions (due to digestion of ruminants) and 65% of nitrous oxide (from manure). Livestock takes place in almost any climate and area of the world, from intensive production systems to those where the animals graze freely. However, it is estimated that livestock, especially meat production worldwide, will increase by double by 2050 (FAO, 2006), thus increasing the environmental impact of this activity, as well as food demand –such as in grassland areas. In this sense, the Intergovernmental Panel on Climate Change (IPCC, 2001) found that the combination of increased CO_2 concentrations and temperature changes along with precipitation will have significant impacts on grassland areas, with increased production in humid regions but decreases in arid and semiarid regions. This situation was confirmed years later in the Fourth Assessment Report (IPCC, 2007).

Grasslands, and generally any other plant, are sensitive to the presence of CO_2 and climate change: impacts on stability and resilience of plant communities can be observed (Mitchell and Cillag, 2001). It has also been confirmed that changes in forage quality and feeding behavior will occur (Easter ling *et al*., 2007). Furthermore it was found that species not palatable for cattle breeding may spread, which may have effects of less nutritional value of these pastures for livestock (DEFRA, 2000).

It has also been identified that climate variability may directly affect livestock, particularly under El Niño and the Southern Oscillation (ENSO) where changes in vegetation´s behavior and water availability take place (Gitay *et al*., 2001). In semiarid regions there is a risk of severe degeneration of vegetation, which may lead to changes in land degradation, and along with less rain, loss of grazing lands and pastures (Zheng *et al*., 2002).

Plant output and vegetal species composition in grasslands is highly correlated to the amount of precipitation (Knapp and Smith, 2001). It is expected for the amount of rain in different regions in México to decrease under climate change conditions (Conde *et al*., 2008). In addition to the latter, it has also been stated that the most vulnerable vegetation types in the country are grasslands, scrubs and oak forests, which have the highest rates of change projected for 2050. Moreover, between 53 and 62% of vegetal communities will be exposed to climate conditions different to the current ones (INE-SEMARNAT, 2006). Out of 198 million hectares of national surface, approximately 16% is for agricultural use, 23% are forests and rainforests and the remaining 61% is rangeland area (PND, 2007), which implies that the national livestock surface is just over one hundred million hectares (COTECOCA, 2002). In addition to the threat of climate change on vegetation, deterioration due to land use caused by the introduction and expansion of livestock must be considered as well (INE-SEMARNAT, 2006). Therefore, the following objectives were proposed for this study 1) evaluate vegetation´s capacity to remain as a food source for livestock, 2) evaluate the net primary productivity and rates of rangeland under present and climate change conditions as a measure to estimate the vulnerability of the sector, and 3) promote awareness on natural capacity and the impact on livestock that can be observed due to climate change.

2. Methods

2.1 Data

The geographical distribution of monthly and annual temperature and precipitation as climate variables for the base scenario in the period from 1950-2000 was taken from Conde *et al*. (2008). Soil information and maps (INEGI, 1998) as well as dominant vegetation distribution in the country (SEMARNAT-UNAM, 2001) was also used for this study. Areas influenced by climate were drawn from a cartographic map overlapping of annual isohyets and isotherms, as suggested by Gómez *et al*. (2008). More than 2000 areas influenced by climate were drawn in all the country, each with their respective average values of temperature and precipitation per month and year. Soil information and vegetation distribution was considered as a base reference to estimate humidity balances.

2.2 Estimation of evaporation and evapotranspiration

The balance of humidity and evapotranspiration were obtained using the method of Thornthwaite (1957) amended version III (Monterroso and Gómez, 2003; Estrada-Berg *et al*., 2008). The first step in calculating the balance is to define soil´s capacity to retain humidity, considering soil type and vegetal cover (CAP). The following step is to calculate potential evapotranspiration (PET), which is the maximum amount of water that can be lost by a continuous layer of vegetation covering the entire area, when an unlimited amount of water is supplied to the soil (Ortiz, 1987). The PET estimate depends on the monthly mean temperature and annual heat index, according to the following:

$$i_j = (tm_j / 5)^{1.514} \qquad (1)$$

Where i_j is the heat index for the month j and tm_j is the mean temperature of month j in ºC. The annual heat index is obtained according to:

$$I = \Sigma (i_j), j = 1, .., 12 \qquad (2)$$

The monthly and annual heat index is dimensionless. In getting the value of (2) the daily value of evaporation (EV) in millimeters can be estimated according to formula (3):

$$EV = 16 \times (10 \times tm_j / I) \qquad (3)$$

For monthly temperature values higher than 26.5 ºC, the EV value must be obtained from tables. From (3) the value of potential evaporation (PET) can be calculated by multiplying the evaporation by a latitude correction factor (cf), taken from the tables.

Next step to estimate the hydric balance is to consider the soil´s humidity storage capacity (CAP) as well as the potential loss of accumulated water (APWL), which depends on the difference between precipitation and potential evapotranspiration:

$$APWL_{i+1} = APWL_i + (P\text{-}PET)_{i+1} \tag{4}$$

$$Storage = CAP \times e^{APWL/CAP} \tag{5}$$

Dunne and Leopold (1978) define storage as the amount of water that a given unit of soil is capable to retain and that is available for plants, depending on the texture and depth of the soil. The humidity deficit (DEF) occurs when precipitation is less than potential evapotranspiration and can be defined as the difference between the amount of water that can potentially be lost in the atmosphere and the amount of water actually lost (Estrada-Berg *et al*., 2008):

$$DEF_i = (P – PET)_i – \Delta Storage_i \tag{6}$$

The last step consists in obtaining the real evapotranspiration (ETR), water surplus and runoff, as presented below:

$$RET = PET – DEF \tag{7}$$

$$Surplus = AL_{i–1} + (P – PET)_i – CAP \tag{8}$$

$$Runoff = (Surplus_i + Runoff_{i-1})/2 \tag{9}$$

Finally, the water balance estimated three indexes: humidity, aridity and precipitation. An approach to a climate classification using the tables and indexes concluded in eight groups of climates: perhumid, humid, sub-humid humid, sub-humid dry, semi-arid humid, semi-arid, semi-arid dry and arid.

2.3 Net primary productiviy (NPP)

Plants, like any other organism, must use energy in biomass production, growth and reproduction. This energy is spent in the respiration process, which in turn releases energy. The energy remaining after respiration and stored as organic matter is the net primary productivity (NPP) (Smith and Smith, 2001). There are two groups of methods to calculate NPP; the indirect and the direct. Direct methods are more accurate since they use a sampling of multiple crops from the vegetation directly from the field and then it is analyzed in the laboratory to obtain the net primary productivity. However, when working in large areas, direct methods are very costly and very time-consuming. To solve this, there are indirect methods or empirical methods, where equations are applied according to climate and biological variables in order to estimate NPP.

Within this group, one of the most frequently used equations is the one proposed by Rosenzweig (1968) and it has been tested in México (Serrano, 1987, Ritter *et al.*, 1999, Alba *et al.*, 2003). Rosenzweig designed a logarithmic equation where the vegetation´s real evapotranspiration (RET) can be used to predict NPP. The principle is that RET simultaneously expresses water availability and sun energy, essential and indispensable factors in photosynthesis. The equation as stated and used in this study is expressed as follows

$$\mathrm{Log}_{(10)}\ \mathrm{NPP} = (1.66 \times \mathrm{Log}_{(10)}\ \mathrm{RET}) - 1.66 \qquad (10)$$

In this equation, NPP refers to the net primary productivity (gMS/m^2/year); RET is the real evapotranspiration in mm / year and DM is dry matter. To apply the formula, RET estimate of the hydric balance previously described was used.

2.4 Dry matter and herbaceous estimation

Considering plants use NPP to produce leaves, thicken stems, branches, roots and to form flowers and fruits, a percentage of the NPP corresponding to the amount of herbaceous production for each of the vegetation´s communities was defined. We analyzed the types of vegetation in the National Forest Inventory (SEMARNAT-UNAM, 2001) and a percentage of herbaceous production was assigned to each vegetation community according to what is presented in Table I. Grassland formations are those with higher incidence of herbs (up to 80% of the NPP becomes grass) and on the contrary, forests provide less herbaceous production due to their structure and composition.

A use factor was later assigned, taking into consideration that animals do not eat all the grass produced in each zone, and we are additionally including species that are not eaten by animals. The use factor was set at 0.5, a normal value for ecosystems (Novillo *et al.*, 2006). Thus, the amount of food available for animal consumption and cattle and cynegetic load is really below to the total NPP, resulting in smaller initial values for dry usable matter.

2.5 Outdoor livestock feeding coefficients

Rangeland is defined as a land with a capacity to produce forage for livestock and wild animals. The rangeland coefficient (RC) is the animal unit- area ratio adequate to maintain a farm production economically and productively permanent, without damaging the natural resource. In other words it is the necessary surface to maintain one animal unit, at its maximum and permanent production in a given area, compatible with the preservation of natural resources. In México, the Technical Advisory Committee for Determining Rangeland Coefficients (COTECOCA) has been the institution responsible for estimating the national RC and has proposed to estimate the RC according to the following function:

$$\mathrm{CA} = [\mathrm{Consumption\ (kgDM/AU/year)}] / [\mathrm{Production\ (kgDM/ha/year)} \qquad (12)$$

where RC refers to rangeland coefficient (AU / ha / year), DM is dry matter and AU is one animal unit. It is estimated that an AU eats as much as 3% of its body weight. COTECOCA (1976) states

Table I. Herbaceous production as a percentage of net primary productivity.

Vegetation community	Herbaceous production (NPP %)
Irrigated agriculture	2
Rainfed agriculture	3
Area with no apparent vegetation, human settlement, water bodies, mangrove, popal and tulare	0
Low open forest and tascate forest	15
Holm oak forest, coastal rossette scrub, and palmar	6
Sacred fir forest	3
Pine forest and gallery vegetation	4
Mountain cloud forest	3
Chaparral; succulent scrub, desert microphile scrub and sarcocaule scrub	7
Coniferous scrub and subtropical scrub	8
Submontane scrub	11
Mezquital	9
Cultivated grassland	80
Induced grassland	60
Natural grassland	50
Forest plantation and sandy deserts vegetation	1
High mountain meadow	40
Suspended irrigation	10
Savannah	45
High and medium evergreen forest, semi-evergreen seasonal forest, deciduous and semi-deciduous forest, low thorn forest, evergreen and sub-evergreen forest, tropical deciduous and semi-deciduous forest, and halophila and gypsophila vegetation.	5

that the daily consumption of one animal unit weighing approximately 450 kg, is 13.5 kg in average, resulting in an annual consumption of 4927.5 kg. It is important to point out that one animal unit stands for an adult cow along with its calf of less than seven months. Based on (12), consumption can be standardized at 4.925 kg / DM per animal unit per year; thus, to estimate it, it is necessary to only obtain the dry matter production value in each of the different ecosystems of the country, taken from the previous chapter

2.6 Climate change scenarios

The general atmospheric circulation models (GCM) used in the study were ECHAM-5, HADGEM-1 and GFDL-CM-2.0 which will be named for simplicity as Echam, Hadley and GFDL; the socio-economic scenarios tested were A2 and B2 (Nakicenovic *et al.*, 2000) for 2030 and 2050 time horizons. The outputs of these models have a spatial resolution of 2.5º x 2.5º and the change rates were taken from Conde *et al.* (2008). The reasons for change in each model were applied on the base maps of climate and water balance previously described and hence the new cartography for assessed climate change scenarios could be obtained

3. Results

3.1 Net primary productivity (NPP)

The NPP represents the net flow of carbon from the atmosphere into green plants per unit of area and time. In México, this parameter is in the range that goes from 0 to 50 000 kilograms of dry matter per hectare per year (kgDM / ha / year). The variation is largely related to the ecological conditions of each region, the amount of energy received, soil vegetation cover and the amount of precipitation. Figure 1 shows the distribution of this parameter in México for the base scenario and the general circulation models for B2 scenario and time horizon to 2050.

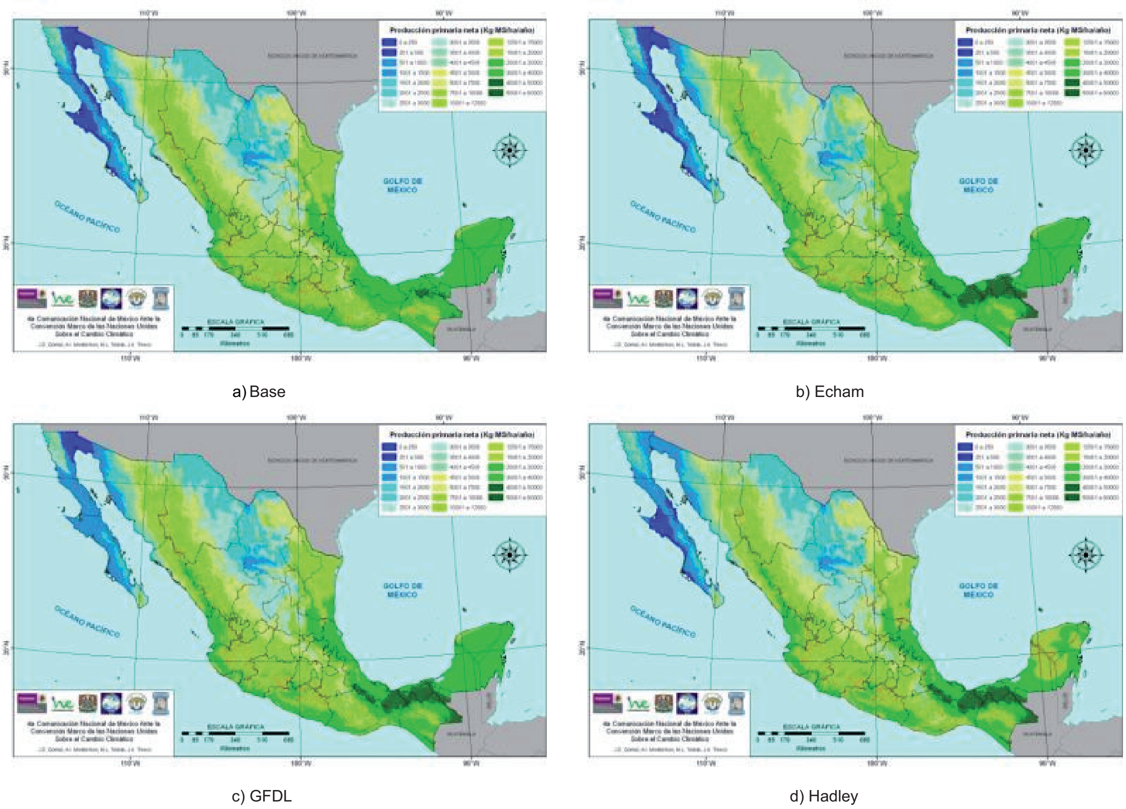


Fig. 1. Net primary productivity (NPP) map. a) Mean 1950-2000 data. Climate change models B2 to 2050: b) Echam, c) GFDL and d) Hadley

3.2 Dry matter estimation

Figure 2 shows the estimated range of DM for the country and the area occupied. About 38% of the land area has a DM production ranging from 0-200 kgDM / ha / year, mainly located in the northern region and in small areas in the central part of the country. It is followed by the range of 500-1000 kgDM / ha / year with approximately 15% of the area. In 76% of the national area it is produced less than 1000 kgDM / ha / year, indicating that three quarters of the country's natural pasture availability is limited. Areas that are located in this range correspond to the dry and semi-arid regions of the country, representing about 50% of national surface (Monterroso and Gómez, 2003), and also to temperate forest areas of closed canopy that limits the production of herbaceous

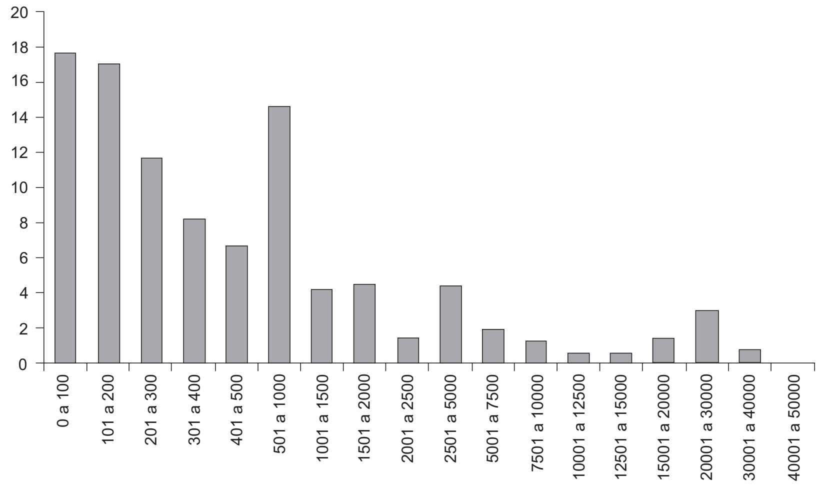


Fig. 2. Range area occupied by dry matter production (kgDM/Ha/year) from herbaceous plants according to the base scenario.

plants. The greater production of DM from herbaceous is generated in grasslands, and due to the ecological character of each site, the range can go from 5000 to 50 000 kgDM / ha / year. The plant communities of tropical and temperate forests have a reduced herbaceous layer and the production of DM in these areas has no higher values, since the canopy is closed and allowed no sunlight, the possibility that the herbaceous layer develops optimally is limited. Thus, the range in which lie these forests, in terms of production of herbaceous plants, goes from 300 to 5000 kgDM / ha / year. The bushes and vegetation of arid and semi-arid areas provide a production of DM from grass in ranges that can go from 0 to 1500 kgDM / ha / year, depending on prevailing rainfall, temperature and solar radiation received, and the type of soil.

3.3 Outdoor livestock feeding coefficients

It was found that the rangeland coefficient (RC) that dominates the country and the base scenario is greater than 20 ha per animal unit, covering about 61% of the total area (Table II). These areas are associated with drier zones and soil as limiting factor for the development of herbaceous plants, that correspond in part to the very arid climate zones estimated by Monterroso and Gómez (2003), plus semiarid areas with dry climate and also soil as limiting factor. On the contrary, the RC of less than 5 hectares covers 15.5% of the national surface and is distributed in small strips, associated mainly to grassland areas in the south of the country where the climate is hot and humid.

Table II. Occupied area (%) by RC range under current conditions.

Rangeland coefficient (ha) per AU	Occupied area (%)
Less than 5	15.5
From 5 to 10	8.7
From 10 to 20	14.6
From 20 to 25	26.7
More than 50	34.5

The RC bigger than 100 ha per animal unit, although it is distributed throughout most part of the country, is located mainly in the north of the country, being Baja California Sur, Coahuila and Sonora the states with larger areas, associated mainly to arid and very dry areas where the grass production is very limited. The production of DM by herbaceous plants in this range is less than 90 kgDM / ha / year. Greater detail of these results is presented in Annex 2.

3.4 Climate change scenarios

The rates of change obtained from each of the general circulation models differ in the variations of temperature and precipitation throughout the year for the different regions of the country. All models predict an increase in temperature, although different for each of the regions. In general, the GFDL presents overall smaller increments but generalized throughout the country and every month. The biggest increase is in Echam, and Hadley model presents intermediate values. This relationship remains across the two time horizons and in both scenarios, differing in each. The increase is higher for 2050 and the A2 scenario. The estimates for precipitation differ between models, while in general the GFDL rates of change have increases in most months, specially in the summer when most of the rain happens, this provision applies to both scenarios and time horizons covered. Instead, Hadley and Echam models presented a trend of lower rainfall, which is accentuated in the A2 scenario for 2050. These conditions have a direct effect on the analysis of NPP, DM and outdoor livestock feeding coefficients. Figure 3 shows the percentage of changes of NPP compared to the baseline scenario.

The changes are more pronounced in the A2 scenario and for 2050, although for each scenario (A2 and B2) patterns of change show great similarity with variations only in the time horizons.

In the A2 scenario for 2030 and 2050 the pattern of variation in the area of the various classes of NPP is very similar. An increase in the bigger class that goes from 40 001-50 000 kgDM / ha / year is observed. This is associated with warm humid areas where no water deficit is expected because they are located in the Gulf of México slope with rain all year. With the increasing of temperature and a proper moisture balance, these zones may enhance their productivity. For all three models an increase from 1.5 to 2.0% is estimated.

In the B2 scenario the impact on productive capacity is lower than in the A2 and follows a similar pattern of involvement in different kinds of DM production, with some variations between classes.

These impacts are transferred to the DM available for grazing, and considering that the NPP is adjusted by a coefficient associated with the type of vegetation, and because it is expected that this remain, the change will be similar for each class, each model scenarios and the time periods considered. This applies to the outdoor livestock feeding coefficients and, for what was discussed in the section, to the variation that they will have.

Figure 4 shows the rangeland coefficients for the base scenario and the socio-economic B2 scenario for 2050 model.

4. Discussion and conclusions

Natural ecosystems in México grow in different environmental conditions that characterize them and that have an influence on the production potential in them. The geographic location of each biome provides distinction, especially in primary productivity. In this sense, the method used to obtain

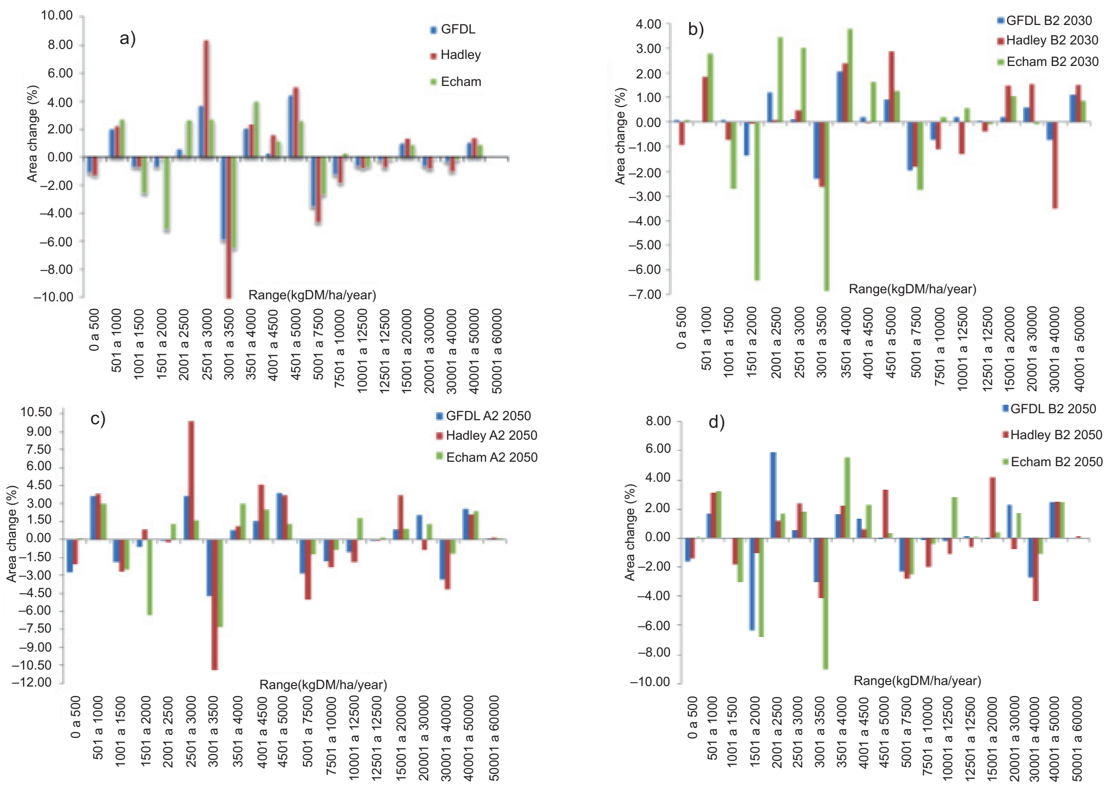
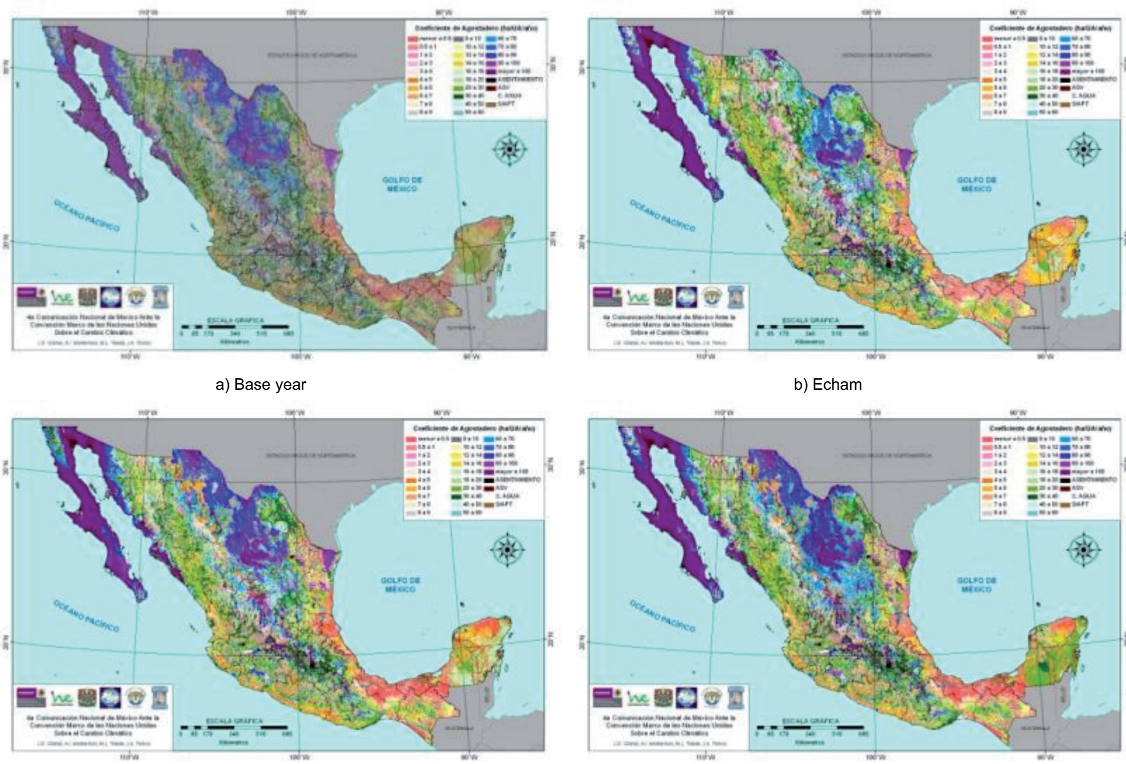


Fig. 3. Change in the occupied area (%) over the baseline scenario of the NPP in accordance with climate change scenarios: a) A2 to 2030; b) B2 to 2030; c) A2 to the 2050 and d) climate change scenarios to 2050

the NPP allowed to correlate the climate and environmental variables for future NPP simulation under climate change scenarios. By using this method we could confirm that the estimates that only consider temperature overestimate the NPP modeling (Ritter *et al.*, 1999). Including hydric balance in modeling allowed a better NPP estimate.

Estimating NPP involves considering different environmental and ecological aspects that at a national level may be overestimated. To apply a preliminary hydric balance helped to better estimate NPP and reduce spatial errors implied in the formula´s application. It is possible that Rosenzweiz´s formula suggests high levels of productivity, so it is recommended to do more studies in order to corroborate its validity and especially its real meaning for more regional scales. In this study it was decided to use the formula given its simplicity of implementation at a national level, although it has not been proven in national studies. It allowed getting more detailed information, with a significant contribution to this work.

In order to obtain more realistic values in estimating the rangeland coefficients, we estimated available dry matter for cattle from NPP values, using herbaceous production factors for plant communities as well as a use factor. This allowed reducing the possible errors in the overestimation of NPP, since herbaceous production factors (Table I) assigned by experts and the use factor (50% of herbaceous production) are reported as normal values for the country's ecosystems.



a) Base year b) Echam

c) GFDL d) Hadley

Fig. 4. Rangeland coefficients for the socio-economic scenarios and B2 scenarios for the 2050 for each model.

In this sense, different potential for herbaceous production for cattle consumption was found in the country, where over half of the national area (60%) had low dry matter production that can be used by livestock, mainly located in areas where rainfall is less than 800 millimeters per year. Moreover, the region where there is greater availability of herbaceous plants is found in the states of Tabasco, Veracruz and Chiapas, among some others, however, these areas represent just less than 5% of the national area.

The lowest dry matter production, i.e. for the range from 0 to 200 kg of dry matter per hectare per year, represent about 60% of the national area and are related to restrictive conditions, such as low rainfall and low soil fertility. If the range is widen –for example from 0 to 300 kgDM / year / ha– the national area increases to 65%. For the case of a range from 0 to 500 kgDM / year / ha, the surface increases to 75%. This suggests that in three quarters of the country it can be fed less than one animal unit per hectare per year naturally, living from extensive grazing, i.e. without shed conditions and in a sustainable manner.

Pastures are where better opportunities to produce food for livestock can take place. The different types of grass can be distinguished by the availability of humidity and temperature, being the humid part of the country the one with the largest natural potential. The tropical region presents the greatest potential for livestock, as it has better conditions for plant growth, mainly linked to high solar radiation and high rainfall.

This affects the definition of rangeland coefficients. The table in Annex 1 compares the values presented by COTECOCA (weighted based on their maximum and minimum estimates) with the results obtained in this study. It is noticed that for eight states the values are practically similar (±10%); for 18 states the required area per animal unit is greater, while in six states the estimates of this study are less than the ones from COTECOCA. It is worth noting the differences found in the states of Chiapas, Colima, Hidalgo, Oaxaca, San Luis Potosi, Sinaloa and Veracruz: information reported by COTECOCA does not exceed 10 hectares required per animal unit, whereas in this study we obtained up to 28ha. Such is the case of Chiapas, where the increase in the area required is of about 1481% (going from 1.8 to 28 ha required per animal unit).

While analyzing the causes for these differences we concluded that they are due to both the cartography used in each study, and the observed changes in land use.

Rangeland coefficients defined by COTECA were for the years 1972-1986, therefore the used cartography fulfilled standards set in those years; however, 20 years have gone by since its publication. In this study, we used cartography from 2001, and the classification and nomenclature of land use coverage are both more detailed and different from those mentioned above. On the other hand we have the changes in land use in the country's ecosystems. The cartography used here was sensitive to such changes occurred since then; they were definitely considered in their spatial representation. The states with greater differences in rangeland coefficients mentioned above –Chiapas for example– agree in having areas covered with forests and rainforests within their boundaries, which are ecosystems that have had major changes in land use since the 80s.

The most favorable rangeland coefficients are located in the Gulf of México, Yucatán Peninsula and South Pacific (particularly in Chiapas), while the less optimal for livestock development are located in the Baja California Peninsula, to the northwest and northeast of the country. This should be regarded as a natural capacity for animal support, because under shed conditions and with greater financial resources, it is possible to increase the coefficients and improve natural capacity.

In applying possible future climate change scenarios, the driest regions of the country increase their vulnerability, and categorically the three models agree on temperature rises, primarily resulting in the reduction of humidity in the soil and affecting the development of herbaceous stratum in ecosystems, thus affecting the capacity of animal support as well. This region and its livestock productivity must be addressed under very specific policies that focus on reducing vulnerability, investing financial resources to compensate for what nature will no longer provide in a natural way. The states that are more vulnerable to these changes are Sonora, Chihuahua and Coahuila.

In the Yucatán Peninsula and specifically in the state of Yucatán, about 13% of its surface has an RC of more than 20 ha / AU / year in the base scenario; change scenarios suggest an increase of 5% up to 18%. In Quintana Roo State, the RC in the range 20-50 ha / AU / year for the base scenario covers 29% and models agree in the possibility of a rise, reaching 55%. In the states of Guerrero, Hidalgo, México, Michoacán, Nayarit and Oaxaca is noted that under change scenarios it is very likely that current conditions are maintained or even slightly improved.

At this point it is important to note that in México the rangeland coefficients determined by COTECOCA are not dynamic and are calculated for natural conditions, i.e. without considering the disturbance caused by misuse or improvements in the conditions of the sites evaluated locally. They are legal and current valid to determine the size of the small cattle property. However, for current management purposes, values here reported are only demonstrative and we point out that they must be adjusted to local and existing vegetation, climate, soil and animal species conditions using the resources of the sites being considered, among other factors. Therefore, climate change scenarios presented here should be taken with caution and its usefulness is for demonstration purposes only in case future research lines are suggested as well as for current schemes in planning and adapting foreseen changes.

In this sense the Special Program on Climate Change (SPCC, 2008) promoted by the federal executive government and that emerged from the National Strategy for Climate Change (NSCC, 2007) shows a strong inclination to focus efforts on reducing emissions through the development of mitigation projects. Although we recognize the efforts described above, we believe that vulnerability must be reduced and to develop better adaptation capacities in the livestock sector in the country.

Specifically in the Program for livestock, two objectives are proposed: reduce livestock vulnerability towards climate change impact and deepen the knowledge on the impacts on and vulnerability of livestock sector towards variability and climate change. As for the second objective we recognize the lack of studies on the subject in the country, so we can only propose research lines, while for the first objective we propose specific guidelines that can be improved.

In this sense, we applaud the federal government's willingness to address climate change impacts in this sector. However, the proposals that focus on reducing vulnerability are perceived as short, since it is necessary to include a biophysical and social dimensions for its evaluation, as well as to determine the adaptation capacity of the sector (Carter, 2007), and to know why and to what it is vulnerable to. It is expected that the results presented here assist in the formulation of public policies, pointing out a starting point for possible impacts on livestock and helping to identify why it would be in some degree of vulnerability. Different climate change models suggest major changes implemented in the number of animals that can be supported in natural ecosystems. The next step, as set out in the SPCC will be to approach producers (especially with low-income) and develop detailed studies that allow to reduce vulnerability and enhance adaptation capacity of the sector.

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Annexes

Annex 1. Rangeland ratios (hectares per animal unit) reported by COTECOCA and compared with those obtained in this study.

State	Adjusted COTECOCA*	Weighted study	Difference %
Aguascalientes	11.56	17.44	51
Baja California	33.92	37.46	10
Baja California Sur	52.17	43.77	-16
Campeche	3.60	5.78	61
Chiapas	1.80	28.45	1481
Chihuahua	20.07	10.72	-47
Coahuila	26.02	6.13	-76
Colima	3.77	20.56	445
Distrito Federal	11.35	8.73	-23
Durango	15.70	16.28	4
Guanajuato	10.20	17.54	72
Guerrero	6.15	7.50	22
Hidalgo	6.41	14.22	122
Jalisco	8.50	9.36	10
México	9.33	14.54	56
Michoacán	7.00	10.74	53
Morelos	10.85	13.92	28
Nayarit	6.35	6.37	0
Nuevo León	22.57	14.49	-36
Oaxaca	4.12	9.79	138
Puebla	7.82	13.46	72
Querétaro	13.49	14.90	10
Quintana Roo	3.72	6.52	75
San Luis Potosí	9.80	17.89	83
Sinaloa	9.07	17.21	90
Sonora	22.36	20.85	-7
Tabasco	1.94	0.77	-60
Tamaulipas	11.35	10.18	-10
Tlaxcala	10.10	14.58	44
Veracruz	1.81	3.39	87
Yucatán	4.37	4.26	-2
Zacatecas	14.49	19.95	38

* Prepared by the Technical Advisory Committee Rangeland coefficients (COTECOCA), Sagar, based on: COTECOCA, SARH, Memoirs of Rangeland coefficients, years 1972-1986, México.

Annex 2. Occupied area (%) for the Mexican States of rangeland ratio range for the base year and climate change scenarios A2 by 2050.

State	Scenario	Rangeland coefficient(ha/AU/year)								Change signal[±]	Change address
		<1	1-5	5-10	10-20	20-50	50-100	>100	Otros[*]		
Aguascalientes	Base		27.1	3.3	12.0	19.8	18.2	17.6	2.0		≈
	Echam		27.2	4.1	12.7	19.0	17.4	17.6	2.1	=	
	GFDL		27.1	3.9	11.4	19.5	18.5	17.5	2.1	=	
	Hadley		26.8	0.9	14.0	16.0	20.5	19.7	2.1	–	
Baja California	Base		0.9	1.0	0.4	11.3	13.0	68.2	5.2		▼
	Echam		0.9	1.0	0.4	10.4	11.0	71.1	5.2	–	
	GFDL		1.0	1.0	0.5	13.1	11.8	67.4	5.2	+	
	Hadley		1.0	1.0	0.3	10.8	18.5	63.2	5.2	–	
Baja California Sur	Base		0.2	0.2	0.5	2.2	5.9	88.8	2.4		▼
	Echam		0.1	0.2	0.2	1.5	5.4	90.1	2.5	–	
	GFDL		0.2	0.1	0.4	3.0	21.8	72.0	2.5	–	
	Hadley		0.2	0.2	0.5	2.2	14.9	79.6	2.5	–	
Campeche	Base	15.0	7.8	11.6	32.3	25.2			8.2		▲
	Echam	15.1	17.9	2.0	48.7	8.2			8.2	+	
	GFDL	15.0	13.8	5.6	46.3	11.0			8.2	+	
	Hadley	14.6	2.1	17.4	6.1	51.1	0.4		8.2	–	
Coahuila	Base		3.6	2.4	4.8	20.3	38.2	30.0	0.8		▼
	Echam		4.2	1.9	4.7	27.9	46.8	13.6	0.8	–	
	GFDL		3.6	2.4	2.3	22.4	38.1	30.5	0.8	=	
	Hadley		3.6	2.0	1.5	23.0	29.7	39.6	0.8	–	
Colima	Base	8.8	1.8	18.2	19.1	32.2	15.8		4.0		▼
	Echam	8.5	1.6	17.6	15.1	35.7	17.6		4.0	–	
	GFDL	8.9	2.6	17.5	21.4	30.0	15.5		4.0	=	
	Hadley	8.7	1.7	18.6	15.1	34.3	17.5		4.0	–	
Chiapas	Base	25.6	7.3	10.6	29.4	18.0	5.1		4.0		▲
	Echam	26.0	9.2	10.7	33.0	14.2	2.9		4.0	+	
	GFDL	25.8	8.8	11.0	31.5	15.6	3.3		4.0	+	
	Hadley	25.6	8.6	12.7	28.3	17.6	3.2		4.0	+	
Chihuahua	Base	0.1	8.4	12.3	8.5	20.5	35.7	13.5	1.0		≈
	Echam	0.8	19.7	4.5	10.9	49.5	9.1	4.5	1.0	+	
	GFDL	0.3	9.0	13.0	7.8	22.6	36.1	10.2	1.0	=	
	Hadley	0.4	8.2	12.9	7.6	20.6	37.6	11.6	1.0	=	
Distrito Federal	Base		5.2		2.3	39.9	6.2	2.7	43.8		≈
	Echam		5.6		2.8	40.2	5.6	2.6	43.2	=	
	GFDL		5.6		2.9	40.2	6.1	2.0	43.2	=	
	Hadley		5.6		2.9	40.6	6.4	1.4	43.2	=	

Annex 2. Occupied area (%) for the Mexican States of rangeland ratio range for the base year and climate change scenarios A2 by 2050.

State	Scenario	Rangeland coefficient(ha/AU/year)								Change signal±	Change address
		<1	1-5	5-10	10-20	20-50	50-100	>100	Otros*		
Durango	Base	0.3	14.6	6.6	16.3	29.8	22.9	8.9	0.5		≈
	Echam	0.5	18.0	4.4	19.9	39.8	14.1	2.9	0.5	+	
	GFDL	0.5	14.4	7.0	17.5	29.5	21.6	9.0	0.5	=	
	Hadley	0.5	14.4	7.0	16.5	30.4	21.4	9.1	0.5	=	
Guanajuato	Base		20.2	2.5	17.0	28.5	9.8	20.1	1.8		≈
	Echam		20.1	3.1	16.7	28.6	9.7	20.0	1.8	=	
	GFDL		20.1	3.2	16.5	28.5	9.8	20.0	1.8	=	
	Hadley		20.1	2.7	16.2	28.1	10.9	20.1	1.8	=	
Guerrero	Base	10.0	8.0	24.9	18.5	34.4	3.0	0.1	1.2		▲
	Echam	11.9	8.6	24.6	20.6	31.1	2.0		1.2	+	
	GFDL	11.5	8.0	25.3	19.2	32.3	2.5		1.2	+	
	Hadley	11.5	7.3	25.8	21.0	30.7	2.4		1.2	+	
Hidalgo	Base	4.7	10.1	3.8	20.2	39.4	12.3	8.1	1.4		▲
	Echam	4.9	10.8	6.4	19.9	38.0	11.1	7.4	1.4	+	
	GFDL	4.9	10.8	7.2	18.2	37.7	11.8	7.9	1.4	+	
	Hadley	4.9	10.7	6.8	16.8	31.3	19.3	8.6	1.4	–	
Jalisco	Base	3.2	17.2	13.8	14.9	41.4	5.5	1.3	2.7		▼
	Echam	3.2	16.8	14.2	15.4	40.7	5.6	1.5	2.7	=	
	GFDL	4.6	16.5	14.3	17.4	38.1	5.3	1.3	2.7	=	
	Hadley	3.7	16.8	14.3	16.2	38.5	6.5	1.3	2.7	–	
México	Base	2.8	12.4	4.7	6.5	50.7	7.9	9.8	5.2		▲
	Echam	3.8	12.1	4.7	7.9	50.5	6.8	9.2	4.9	+	
	GFDL	3.9	11.8	5.0	7.7	51.1	7.0	8.7	4.9	+	
	Hadley	4.0	11.9	4.8	7.7	47.0	11.3	8.5	4.9	–	
Michoacán	Base	2.9	10.8	17.1	13.3	41.2	11.2	0.9	2.5		≈
	Echam	4.4	8.8	18.8	14.7	39.5	10.4	0.7	2.5	=	
	GFDL	4.2	9.7	18.4	14.9	39.5	10.1	0.6	2.5	=	
	Hadley	3.7	9.8	19.1	14.0	40.1	10.3	0.6	2.5	=	
Morelos	Base	0.3	5.3	14.2	2.4	53.4	20.1	0.2	4.1		≈
	Echam	2.0	3.7	14.9	10.3	45.4	19.6	0.1	4.0	=	
	GFDL	2.1	3.6	14.6	15.1	40.9	19.6	0.1	4.0	=	
	Hadley	2.0	3.7	14.4	6.2	50.0	19.7		4.0	=	
Nayarit	Base	9.3	15.6	13.0	26.6	29.6	0.7		5.2		≈
	Echam	9.7	16.1	12.7	27.4	28.4	0.6		5.1	=	
	GFDL	11.3	15.5	12.3	29.6	25.7	0.6		5.1	=	
	Hadley	8.7	17.8	12.1	28.3	26.8	1.2		5.1	–	
Nuevo León	Base	0.3	18.3	4.9	20.3	29.5	17.2	8.2	1.2		▼
	Echam	0.3	18.5	4.5	20.4	29.0	17.9	8.3	1.2	=	
	GFDL	0.4	18.3	4.8	19.6	30.1	17.4	8.3	1.2	=	
	Hadley		18.4	3.3	14.4	34.2	18.0	10.5	1.2	–	

Annex 2. Occupied area (%) for the Mexican States of rangeland ratio range for the base year and climate change scenarios A2 by 2050.

State	Scenario	Rangeland coefficient(ha/AU/year)								Change signal[±]	Change address
		<1	1-5	5-10	10-20	20-50	50-100	>100	Otros[*]		
Oaxaca	Base	7.4	10.0	11.1	22.3	37.4	7.5	1.5	2.9		≈
	Echam	7.6	11.7	11.6	25.6	33.7	6.1	0.9	2.9	+	
	GFDL	7.6	11.1	11.9	24.0	34.6	7.0	0.9	2.9	=	
	Hadley	7.4	11.0	12.0	24.0	33.0	7.9	1.9	2.9	–	
Puebla	Base	4.6	6.7	6.2	14.5	50.7	9.8	5.4	2.0		▼
	Echam	4.9	6.6	8.5	15.8	47.8	10.3	4.2	1.9	=	
	GFDL	5.0	6.5	9.2	15.5	47.5	10.2	4.2	1.9	=	
	Hadley	4.8	6.6	8.2	14.4	45.5	13.2	5.5	1.9	–	
Querétaro	Base	0.2	7.8	6.1	17.0	48.8	10.5	8.3	1.4		▼
	Echam	0.3	8.0	6.4	18.9	46.8	10.1	8.0	1.4	=	
	GFDL	0.3	8.0	6.1	18.5	44.2	13.4	8.0	1.4	–	
	Hadley	0.3	8.0	5.7	16.1	45.4	15.0	8.1	1.4	–	
Quintana Roo	Base	7.9	8.5	6.9	36.0	29.9			10.8		≈
	Echam	7.9	15.3	0.4	62.7	2.8			10.9	+	
	GFDL	7.9	15.1	0.3	63.0	2.8			10.9	+	
	Hadley	7.8	0.5	15.0	5.4	60.2	0.2		10.9	–	
San Luis Potosí	Base	7.1	5.6	6.6	15.2	25.6	29.3	9.9	0.8		▼
	Echam	7.1	6.9	6.2	15.5	26.4	29.2	7.9	0.8	=	
	GFDL	7.1	5.9	7.5	15.4	24.2	29.2	9.9	0.8	=	
	Hadley	7.1	5.9	6.5	14.9	23.8	30.3	10.5	0.8	–	
Sinaloa	Base	0.9	2.3	10.7	14.4	42.7	6.6	17.6	4.8		≈
	Echam	1.5	2.6	11.7	20.8	37.9	5.7	15.0	4.9	+	
	GFDL	1.2	2.1	11.0	16.0	40.8	6.5	17.4	4.9	=	
	Hadley	1.0	2.3	10.5	15.5	40.0	8.4	17.4	4.9	–	
Sonora	Base		10.5	2.3	11.1	35.7	16.8	21.7	1.8		▼
	Echam	0.9	10.4	7.7	14.8	32.2	11.6	20.6	1.8	+	
	GFDL	0.1	11.0	2.8	16.8	33.7	13.2	20.4	1.8	–	
	Hadley	0.2	9.1	3.3	10.2	33.6	19.2	22.7	1.8	–	
Tabasco	Base	54.7	4.1	11.7	3.9	0.5			25.1		≈
	Echam	54.5	4.6	12.6	2.7	0.5			25.1	=	
	GFDL	54.5	4.5	12.1	3.1	0.5			25.1	=	
	Hadley	54.5	4.6	10.9	4.4	0.5			25.1	=	
Tamaulipas	Base	9.9	12.0	11.3	24.9	23.2	13.7	2.2	2.6		▼
	Echam	9.4	12.3	11.1	25.2	23.2	5.9	10.2	2.6	–	
	GFDL	9.4	12.6	10.4	24.3	24.2	7.3	9.2	2.6	–	
	Hadley	7.4	14.1	9.2	20.4	27.9	6.5	12.0	2.6	–	
Tlaxcala	Base		8.1	2.2	4.2	73.9	4.3	5.9	1.3		≈
	Echam		8.3	2.5	4.5	73.4	4.5	5.6	1.2	=	
	GFDL		8.3	2.5	4.8	73.2	5.5	4.5	1.2	=	
	Hadley		8.3	2.3	4.8	65.1	13.8	4.4	1.2	–	

Annex 2. Occupied area (%) for the Mexican States of rangeland ratio range for the base year and climate change scenarios A2 by 2050.

State	Scenario	Rangeland coefficient(ha/AU/year)								Change signal±	Change address
		<1	1-5	5-10	10-20	20-50	50-100	>100	Otros*		
Veracruz	Base	48.1	5.3	8.8	24.6	7.2	1.9		4.2		▼
	Echam	48.0	5.3	13.4	20.8	6.7	1.6		4.2	=	
	GFDL	48.0	5.6	13.9	20.0	6.1	2.2		4.2	–	
	Hadley	48.0	5.2	13.2	20.9	6.2	2.2		4.2	–	
Yucatán	Base	21.6	10.7	23.8	25.6	13.5	0.2		4.5		▼
	Echam	21.7	28.1	6.3	35.5	3.6	0.2	0.1	4.6	–	
	GFDL	21.6	18.2	16.3	31.7	7.4	0.3	0.1	4.6	–	
	Hadley	20.5	1.8	31.0	22.4	17.8	1.9	0.1	4.6	–	
Zacatecas	Base		14.3	7.8	5.9	24.4	35.6	11.6	0.5		≈
	Echam		16.3	6.7	5.8	34.3	30.0	6.4	0.5	+	
	GFDL		14.3	8.3	5.3	24.9	35.2	11.5	0.5	=	
	Hadley		14.3	7.7	6.0	24.9	34.2	12.5	0.5	=	

* Others refer to water bodies and urban areas. ± Change signal refers to the analysis of the trend observed by the simulation under climate change scenarios, placing greater emphasis on rangeland ratios greater than 50 ha/AU/year in the country. An equal sign (=) refers to current conditions is likely to remain, a plus sign (+) refers to possibly improve natural areas with availability for the livestock feed and a negative sign (-) to probably surfaces with natural availability decrease. Change address was considered as the sign of change as the trends in the models for all ranges of the coefficients of rangeland, an approximately equal sign (≈) refers to possibly maintain the current conditions, a downward arrow (▼) emphasizes that the changes specified by the scenarios mean less favorable conditions for livestock to increase the restrictive conditions for livestock and finally an up arrow (▲) indicates that under climate change scenarios can be observed better conditions for the natural feeding of the livestock.