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Report of the application of GEOMOD to Chiapas, Mexico region

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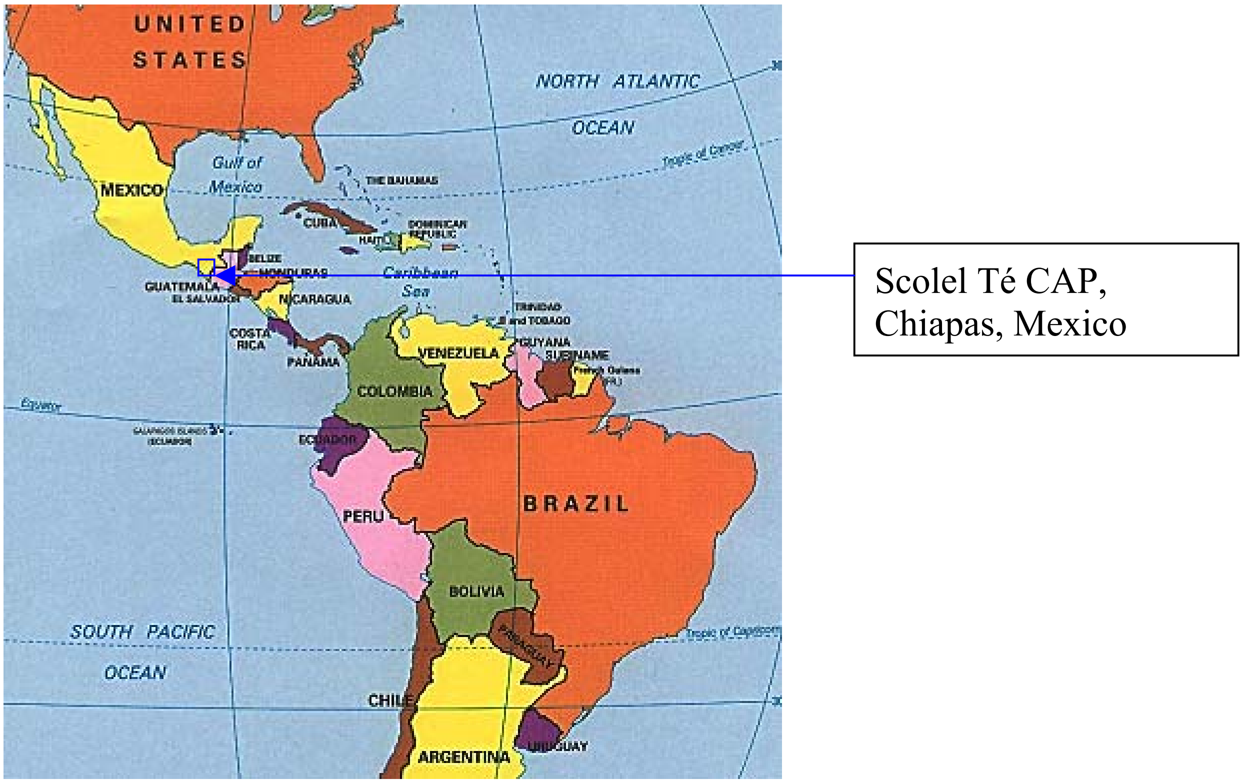
Spatial modeling of the averted deforestation baseline for the Scolel Té Region of Chiapas, Mexico, 1996 – 2030.



Submitted to Winrock International

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I. BACKGROUND

A.1. Project Description

The Scolel Té Project in Chiapas, Mexico is an effort to estimate how the region might benefit from the implementation of carbon offset projects where, in return for protecting carbon stored in forests, the project area receives payments under the proposed Kyoto Protocol guidelines for carbon offset projects. Central to the planning for carbon offset projects, however, is some sort of analysis that can show that the project, if implemented, will actually result in protection of stored carbon that without the project would have been lost. Under current Kyoto Clean Defense Mechanism guidelines, protection of forest resources that are not under threat of deforestation, would add nothing to the global carbon sink, and would, therefore, not be eligible for carbon offset credits.

The primary purpose of this research project is to estimate the "without project" distribution of land-use change that can be expected in the region in order to create a baseline estimate against which potential projects can be measured. To do this we applied a general model of land-use change called GEOMOD to spatially-georeferenced data of the region in order to simulate the potential distribution of land-use change, and particularly deforestation from 1999 to 2030 A.D.

A.2 The List of Players

This reports is the result of interactions between two different groups of researchers; namely Ben de Jong's group at El Colegio de la Frontera Sur (ECOSUR) in Mexico (Chiapas and Tabasco) and Geographic Modeling Services (GMS), Syracuse, NY. This report is based in part on data and information delivered to the GMS group during a visit by Miguel-Angel Castillo who is a member of Ben de Jong's research group. During May of 2001, Miquel-Angel Castillo came to Syracuse, New York to interact with the research group led by Myrna Hall.

Over several days, Miguel-Angel briefed the Syracuse team on various aspects of the Scolel Té project including the previous analyses of land-use change and carbon loss performed by the ECOSUR group. Miguel-Angel's presentation included a detailed description of the study area, upon which we base our report. From our interactions with Miguel-Angel, we were able to build up an understanding of how people in the region use land, and how that knowledge could be applied to a model of LUC (GEOMOD) to predict the distribution of future land-use change in the region.

The result is a summary of how future changes in the region will most likely affect the distribution of land use; primarily the loss of forest cover due to deforestation. We did not, however, continue with this analysis to include a consideration of the loss of carbon due to future land-use change.

A. 3. The Scolel Té Project Area

The project area is located in the southwestern region of Chiapas, Mexico. The region was subdivided into four “ecoregions” based on similarities in climate and land cover (Figure 1). Furthermore, each region differed in its social and demographic dynamics and in turn, these differences have influenced the rate of deforestation in each region (Table 1.)

The "Selva" comprises the eastern-most, lowland rainforest. Vegetation is broadleaf evergreen forest. The area consists of 552856 hectares and is home to the Lacondon Maya, but since the 1980's has increasingly been opened up by the Mexican government for (1) oil exploration, (2) resettlement from other parts of Chiapas, and (3) settlement of refugees from Guatemala. According to Miguel-Angel, the Guatemaltecos do not necessarily deforest land for themselves, but instead get hired as ranch hands helping the local cattle ranchers cut down forest. Between 1975 and 1996, about 28% of the forest was cut down for pasture and agriculture.

The "Reserva" is the area within the "Reserva de la Biosfera Montes Azules" and is home to Lacondon Maya. The Reserva is the smallest sub region at 317,485 hectares. Vegetation consists of lowland tropical, broadleaf evergreen forest. According to Miguel-Angel, forest regrowth in the Reserva and in the Selva is so rapid it is impossible to separate disturbed from undisturbed forest in the 1996 remote sensing image. LUC in this area has been very light. Between 1975 and 1996, only about 22720 hectares (roughly 7%) of the area was deforested.

The "Canad" area is the transitional zone between the lowlands and the highlands of Chiapas. According to Miguel-Angel, it is also the most geographically diverse and biologically rich, containing lowland tropical forest, cloud forest, and mixed oak and needle leaf montane forests. The Canad is also the largest sub-region consisting of 965,966 hectares. Between 1975 and 1996, more than 43% of the forest was cut down for pasture and agriculture.

The "Alta" represents the Chiapas highlands located on the western-most side of the study region. The temperature is much cooler and the rainfall much less than in the lowlands to the East. The Alta is the most densely populated, and at 703,752 hectares, the second-largest area in the Chiapas study area. The vegetation consists of montane forest (mixed semi-deciduous and needle leaf evergreen forest and some cloud forest.)

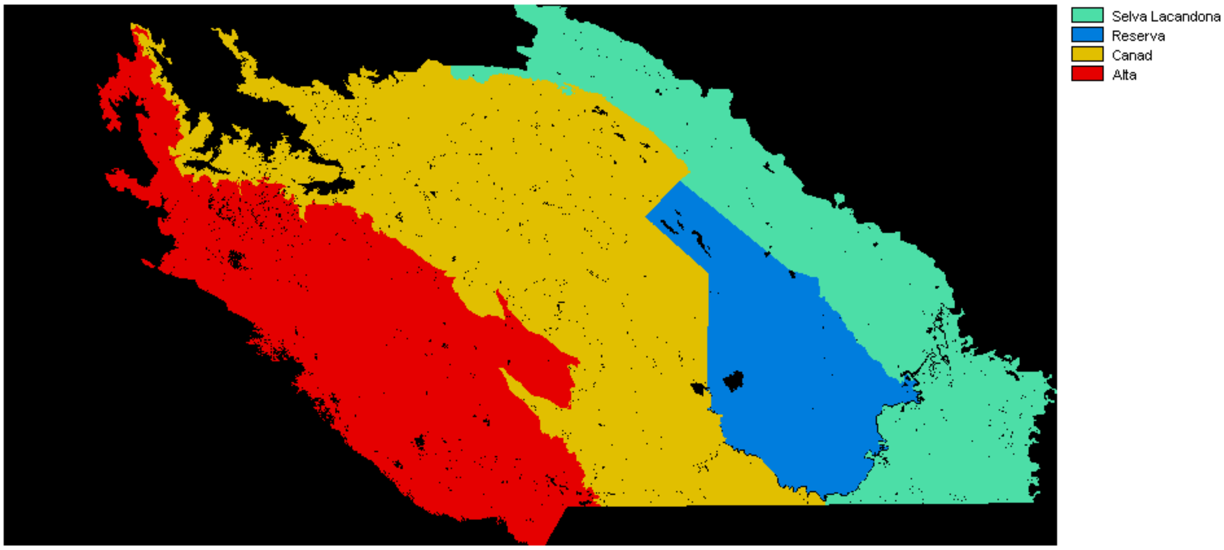


Figure 1. Ecoregions of Chiapas, according to ECOSUR definition.

TABLE 1. Historical Forest Cover Change Statistics for the Chiapas Region 1975 – 1996 *				
Region	Area (ha)	% Area Deforested 1975-1996	Average Area Deforested per Year (ha)	Avg. Annual Rate of Population Growth 1975 - 1996
La Selva	552856	28.2	6996	3.46
La Reserva	317485	7.2	1082	3.37
La Canad	965966	43.4	17908	2.43
La Alta	703752	37.0	9344	1.86
Total	2540059		35,330	

* The information in TABLE 1 above was derived from two maps of land use/land cover and Mexican Census data provided by Miguel Angel Castillo and are described in the next section.

DATA

B.1 Data Sources and Processing

The GIS data analyzed in this report were supplied by Miguel Angel Castillo of ECOSUR and were manipulated in Syracuse for use in GEOMOD. The original data were obtained from satellite imagery of land use/land cover for 1996 and from digitized maps, most notably, the "Uso de Suelos" map of Mexico which was based on information from approximately 1975. The resolution of the raw input data ranged from 25 meters for the satellite imagery to 100 meters for the digitized maps. The original 25-meter resolution data contained 12435 columns by 6384 rows. Each grid cell represented only 0.0625 ha. Assuming that the most likely unit of land use change is one hectare we decided to use the 100 x 100 meter resolution for all data. The resulting maps are composed of 3109 columns and 1596 rows. At this resolution every grid cell represents 1 hectare. The 1975 and 1996 land use/land cover maps were reclassified as follows: 1 = forest, including both intact forest and that already impacted by human activity; and 2 = deforested, i.e. all land in agriculture or pasture (Figure 2). The 1996 map land cover categories were used for carbon calculation (Figure 3). Seven potential spatial pattern drivers (Table 2) were evaluated alone and in combination by GEOMOD and results from each test were validated against the 1996 LU map (Figure 2).

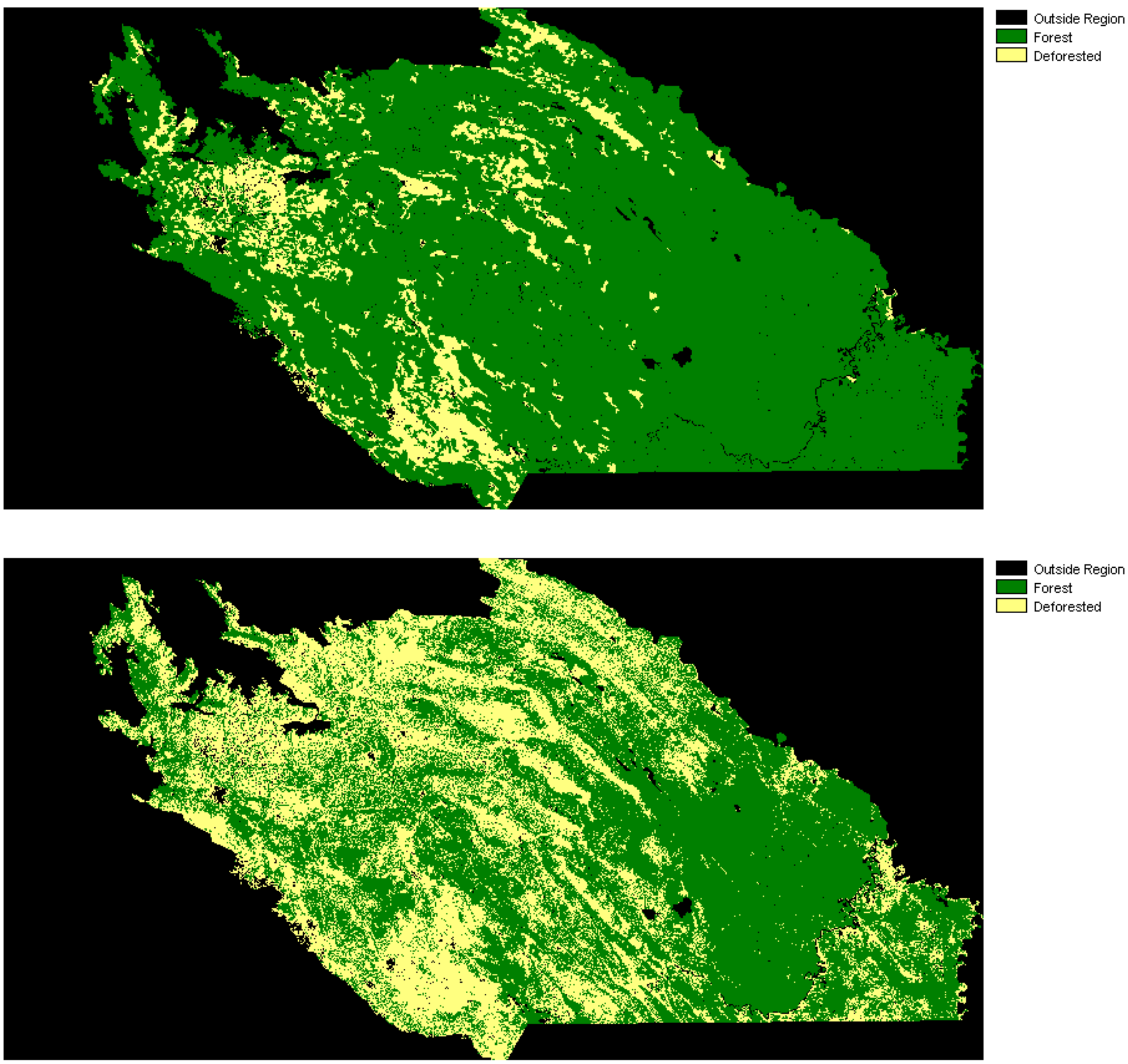


Figure 2. 1975 and 1996 Chiapas land use/cover maps reduced to two classes.

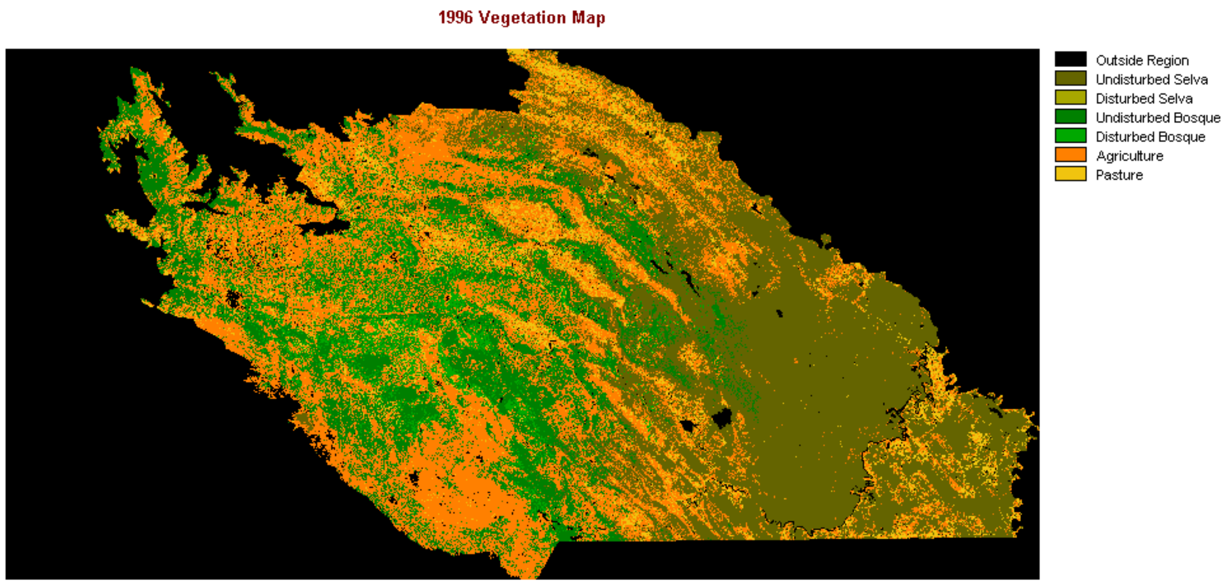


Figure 3. Map of 1996 Land Cover/Use in Chiapas, Mexico

TABLE 2. Driver Maps Tested by GEOMOD

* DIST2RD2	(Distance to Road Network circa 1980) 1 = from 0 to 1000 meters near roads 2 = 1000 to 2000 meters from road 3 = more than 2000 meters from road
** DIST2AG2	(Distance from 1975 agriculture) 1 = all non-forest in 1975 plus the surrounding 500 meters buffer 2 = between 500 meters and 1000 meters from non-forest in 1975 3 = beyond 1000 meters from non-forest in 1975
* POPDEN90	(Density of "agricultural" population in 1990 1 = 0 inhabitants per km² 2 = 1 - 15 / km² 3 = 15 - 30 / km² 4 = > 30 / km²

* MARG (Level of Marginalization "Poverty") 1 = most impoverished 2 = second most 3 = second least 4 = least impoverished
*** 1975LULC (Distribution of LU/LC in 1975) 1 = undisturbed lowland selva 2 = undisturbed highland bosque 3 = all non-forest and disturbed forest
* Land Tenure
** Slope derived from a digital elevation model (DEM)

* provided and tested by ECOSUR; ** created by GMS; *** provided by ECOSUR, tested by GMS

B. 2. Analysis of LUC Matrix

In preparation for running GEOMOD, an analysis of the two maps of forest cover was performed using GIS to help us understand the dynamics of the actual LUC that took place in the region between 1975 and 1999. The two maps of LU were compared using the CROSSTAB function in IDRISI. This analysis can be used to generate a conversion matrix showing the percentage of each land use/land cover type for 1975 that is converted into each land use/land cover type in 1996. The results are summarized in an EXCEL spreadsheet (BLOCK.XLS) and show several interesting trends. One trend is the high probability for disturbed forests to be converted into pasture and agriculture. Between 1975 and 1996 65% of the area in disturbed "selva" and 54% of the disturbed "bosque" was converted into pasture and agriculture.

Another interesting trend was that about 19% of the area in both agriculture and pasture in 1975 were classified as either disturbed or undisturbed forest in the 1996 remote sensing image. This amount seems too large to just be an artifact of image classification, and instead probably reflects real forest regrowth. Even with this forest regrowth, however, it is clear that the overall net trend has been the conversion of forest into pasture and agriculture.

In addition to the drivers evaluated by the ECOSUR team, which included 1) marginalization of the population, 2) land tenure, 3) density of people who work the land for their livelihood, and 4) distance from roads, we tested distribution of 1975 land cover, distance from 1975 agriculture and slope of the terrain.

The GIS analysis was also used to provide data on the net amount of deforestation that occurred between 1975 and 1996 for use in GEOMOD. GEOMOD simulates only the distribution of LUC over time and must be given the information on the amount of change that will take place during each time interval. The net amount of deforestation is used by GEOMOD to derive the annual rate of change.

II. APPLICATION OF GEOMOD – METHODS EMPLOYED

GEOMOD is a general model of land-use change that compares maps of potential drivers with maps of actual land use, weights all map cells according to that analysis (i.e. the importance of each driver in explaining previous land use change patterns) and then simulates LUC over time based on that comparison. GEOMOD requires that the operator enter information regarding the amount of land-use change that will take place during each time era and then simulates the distribution of that change over the landscape. GEOMOD evaluates the success of each simulation based on a percent correct scale as compared to maps of actual land-use change and based on how well the model performed as compared to the expected success due to chance. The model performance versus that due to chance is summarized using the kappa statistic.

Before running GEOMOD, information must be entered into two setup files which tell the program which GIS files to use, what type of output is desired, and how GEOMOD is to deal with different types of situations such as whether GEOMOD is starting with an area with no development at all, or starting in a developed area. In addition, several additional parameters need to be adjusted to maximize model performance.

II. A. Calibration of Model - Adjustment of parameters

We set up GEOMOD with the data for Chiapas and test runs were made to set the size of the search window to be used and to adjust the number of classes used to represent each driver map.
The selection of how large the search window should be requires that several runs be made using progressively smaller windows until the optimum (based on the accuracy of the model results) is found. If the search window is too small, GEOMOD cannot complete that simulation and will send an error message telling the user to increase the search window size. If the search window is too large GEOMOD will run, but the model accuracy suffers and the time needed to complete a simulation is increased needlessly. After several runs, a search window of 10 cells (10 ha) was found to provide the best model results.

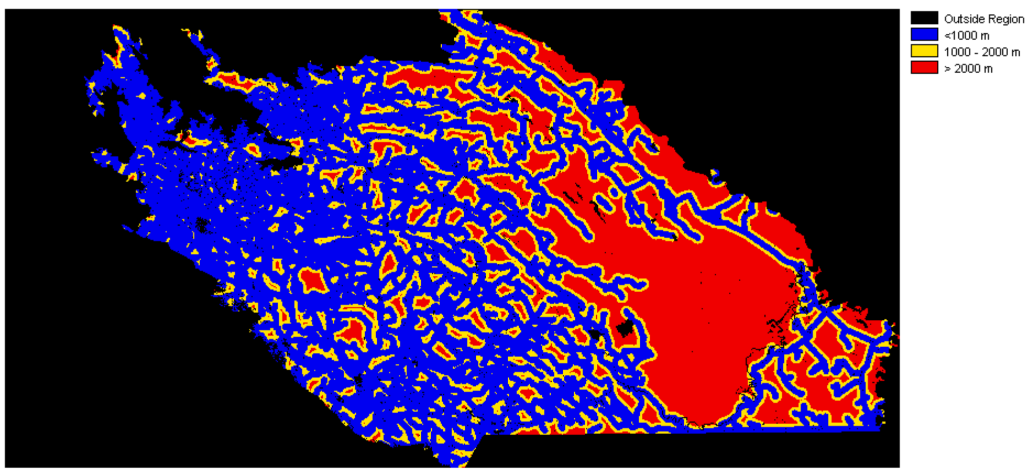
Next we ran additional test runs to find the best class sizes for several of the GIS images used as driver maps. As each run was performed, the percent correct and kappa statistic for each map was noted and the classes adjusted until no further improvements were observed.

II. B. Validation of Driver Maps

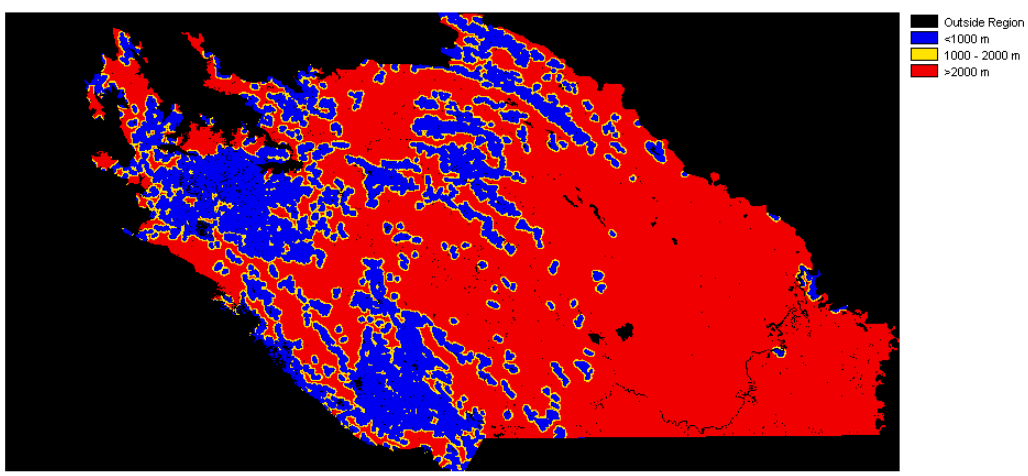
The seven potential driver maps listed in Table 2 were evaluated using GEOMOD. GEOMOD was set up to test all possible combinations of driver maps to see which individual map could best simulate the distribution of LUC between 1975 and 1996 as well as the best possible combination of maps. The best possible combination used five maps (distance to roads, distance to previous agriculture, population density, population density in 1990, level of marginalization, and distribution of land use/land cover) (Figures 4-8). The best combination resulted in a percent correct of 71.6%

and a kappa statistic of 0.22 showing that GEOMOD was significantly outperforming the results due to random chance (Table 3). The highest percent simulated correctly when validated against the 1996 map of the region was the distribution of the land cover in 1975 and the “land employed” population density map. This is not surprising since the density map was for the year 1990 and not 1975, and the land cover driver was set up to capture prior knowledge of what actually happened, i.e. what vegetation classes the majority of the 20 year clearing had come from. This is not “cheating,” however, as we could have set up the land cover map a number of ways to test this, even without knowledge of the 1997 pattern of development. This knowledge saved time. The same knowledge was also available from Ben DeJong (personal communication).

Distance from Roads



Distance to 1975 Agriculture



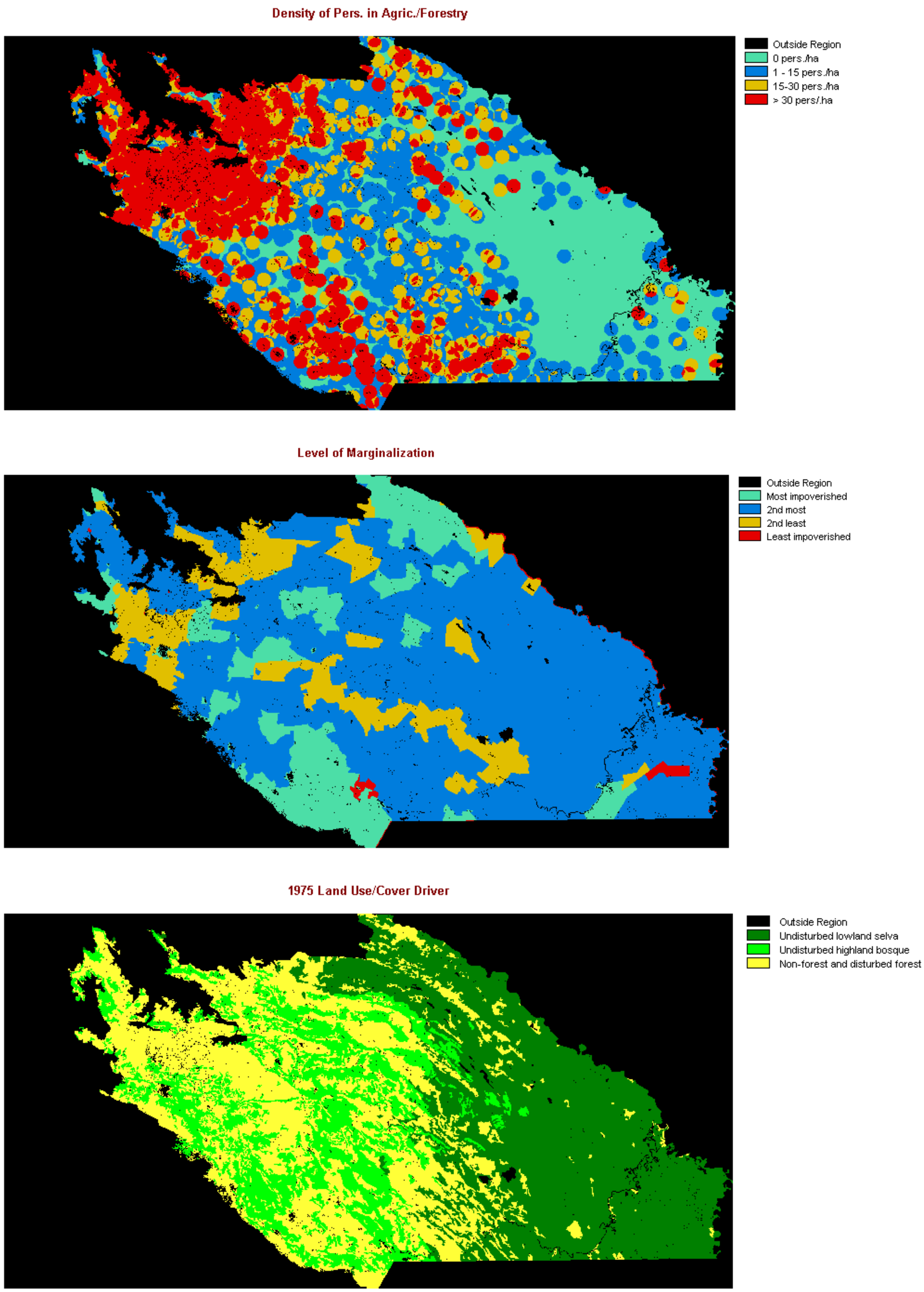


Figure 4. Five Spatial Pattern Drivers that together yield the best validation results when compared to actual 1997 land use map.

TABLE 3. Results of GEOMOD Evaluation of Drivers		
Driver	% Success	Kappa Statistic
Distribution of 1975 LULC	68.6052	0.1388
Population Density	68.4589	0.1348
Distance to Roads in 1980	66.8661	0.0911
Distance to Agriculture in 1975	65.2587	0.0471
Level of Marginalization	64.8642	0.0362
Land Tenure	63.7298	0.0051
Slope	62.8531	-0.0190
No Drivers (GEOMOD alone)	62.1006	-0.0396
Expected Success Due to Chance	63.5447	
Veg+Pop+Road+Ag+Marg	71.5734	0.2202

In the case where GEOMOD is run alone without any driver maps, the model selects each additional unit of land to change based solely on GEOMOD's internal rules such as proximity to previous land use and contiguity with previous land use. Again for comparison, the best combination of drivers resulted in a percent correct of almost 71.6% and a kappa value of 0.22.

This shows that GEOMOD can take advantage of the additive effect of including additional driver maps. Furthermore, this analysis allows us to quantify the usefulness of each driver map and to select the best driver maps for simulating land-use change into the future. Based on this evaluation, the five driver maps and the relative weights assigned by GEOMOD were found to be acceptable for trying to simulate the future distribution of land-use change in the region. The model creates a map of susceptibility or vulnerability to deforestation (Figure 5) where each cell is weighted in comparison to all others depending on its importance in each of the five final driver categories. Note that the Reserva region based on analysis of all drivers, and current forested state, appears to be under no threat. All that remains to be determined in order to run GEOMOD into the future then is some estimate of the amount or area of land-use change that is likely to occur.

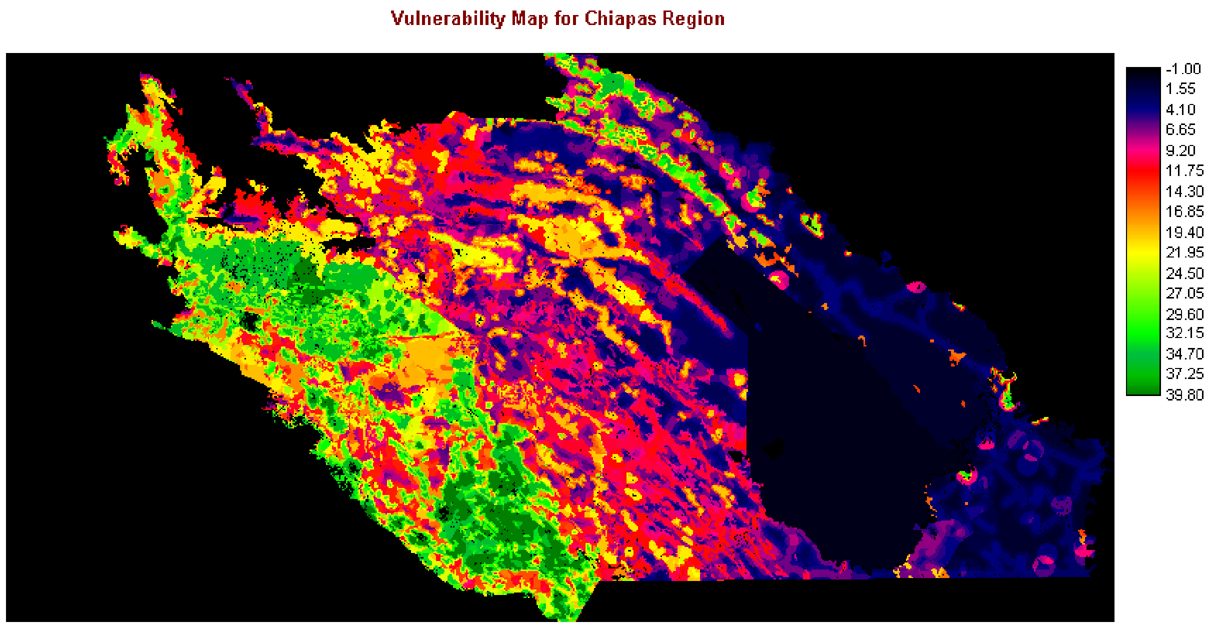


Figure 5. The map of vulnerability predicted by GEOMOD based on the 1975 to 1996 deforestation versus five best drivers. Green areas are either already deforested or most likely to deforest post 1975.

II. C. Rate Derivations

We used two methods to estimate the amount of future land-use change, a business-as-usual rate based on the average yearly loss of forest in each region between 1975 and 1996, and an exponential rate tied to the rate of population growth in each region.

II. C.1. Business as Usual

In the business-as-usual scenario, the amount of forest cover remaining in 2030 was estimated by multiplying the regional yearly rate by 34 (the number of years of the simulation). Then, GEOMOD was run for the period 1996 to 2030 and created output maps showing the distribution of forest/non-forest for every two years from 1998 to 2030 (17 maps). This scenario is based on the assumption that at least as much land-use change per year will occur in the future as has occurred in the past. This scenario could also be considered the low-end or perhaps even the "best case" scenario for the region.

II. C.2. LUC Tied to Population Growth

We believe that the change seen over the period of calibration, i.e. 1975 – 1996, was not linear, but rather some exponentially increasing amount. We, therefore, simulated a second scenario based on the population trends observed in this region. Based on our findings in other regions (e.g. in the Bolivian Amazon), there is normally high correlation between numbers of people in a region and the rate of deforestation. With data for only two points in time we could not test this assumption in this region. To generate the maps of land-use change as a function of population growth, a model (LUC.FOR) was written to calculate the amount of deforestation that would occur in each region each year based on (1) the previous average yearly deforestation rate and (2) that region's population growth rate (Table 4). The idea here was that as the population grows in each region, an increasingly larger amount of forest will be converted each year to non-forest. The output from LUC.FOR (Table 1, Appendix) was used to create 17 separate sets of setup files and GEOMOD was run 17 times to generate the 17 maps of LUC from 1998 to 2030 based on population growth.

II. C.3. The 5 Percent Rule

In both scenarios, in each region, deforestation was forced to cease once all but 5% of the regions total area was deforested. This was done to reflect the fact that it is relatively difficult, and also relatively unusual to see 100% deforestation in any given region. In other words, it would appear that a "saturation" point is reached after which, all the land that can be, or will be deforested already has been deforested. The level of 5% was chosen to reflect the fact that each sub region, and the state of Chiapas itself, is relatively small. In comparison, the country of Costa Rica, which is roughly 300 times larger, still retains about 15% of its closed cover forest, and even larger countries such as Honduras retain still more of their original forest cover. Conversely, the smaller the area, the more vulnerable the area is to almost total deforestation. For example El Salvador only has about 3 – 4% of its original forests and the islands of Cuba and Puerto Rico experienced the loss of about 96% of their original forests, although the forest cover of Puerto Rico has recovered greatly.

Using our rate of deforestation based on linear extrapolation of the past, only the Canad and Alta regions would have experienced a total loss of forest had the 5% rule not been invoked. But, in the scenario based upon exponential growth, three regions would have lost all their forest cover causing the 5% rule to be invoked. Only the Reserva region would not need to have invoked the protection of the 5% rule by the year 2030 under this scenario.

III. RESULTS

III. A. Quantity of Land Cleared

In 'scenario one,' the linear extrapolation method, 1,015,728 hectares of forest are projected to be lost between the years 1996 and 2030 resulting in a total of 2.06 million hectares, or 82% of the area deforested (Table 4). Under 'scenario two,' i.e. the exponentially projected future, where land use change is modeled as a function of population growth, a total of 1,156,781 hectares would be deforested between 1996 and 2030 for a total of 2.2 million hectares, or 87% of the region impacted by human activity (Table 4). In the exponential scenario, as early as 2005 the amount of forested land versus deforested in the region is approximately equal (Figure 6a). This happens a little earlier in the second scenario (Figure 6b).

Table 4. Chiapas, Mexico GEOMOD 1996 - 2030 Projected Land Use/Land Cover Change				
	Based on 1975 – 1996 Linear Trend		Based on Projected Exponential Population Growth	
Region	# Ha deforested	% Remaining Forest Cover	# Ha deforested	% Remaining Forest Cover
La Selva	237,864	24.5	345,669	5.0*
La Reserva	36,788	81.2	70,035	71.0
La Canad	442,646	5.0 *	442,646	5.0*
La Alta	298,430	5.0 *	298,430	5.0*
Total Region	1,015,728	18.0	1,156,781	13.2

* Region where deforestation was halted when only 5% of the region's forest cover was left

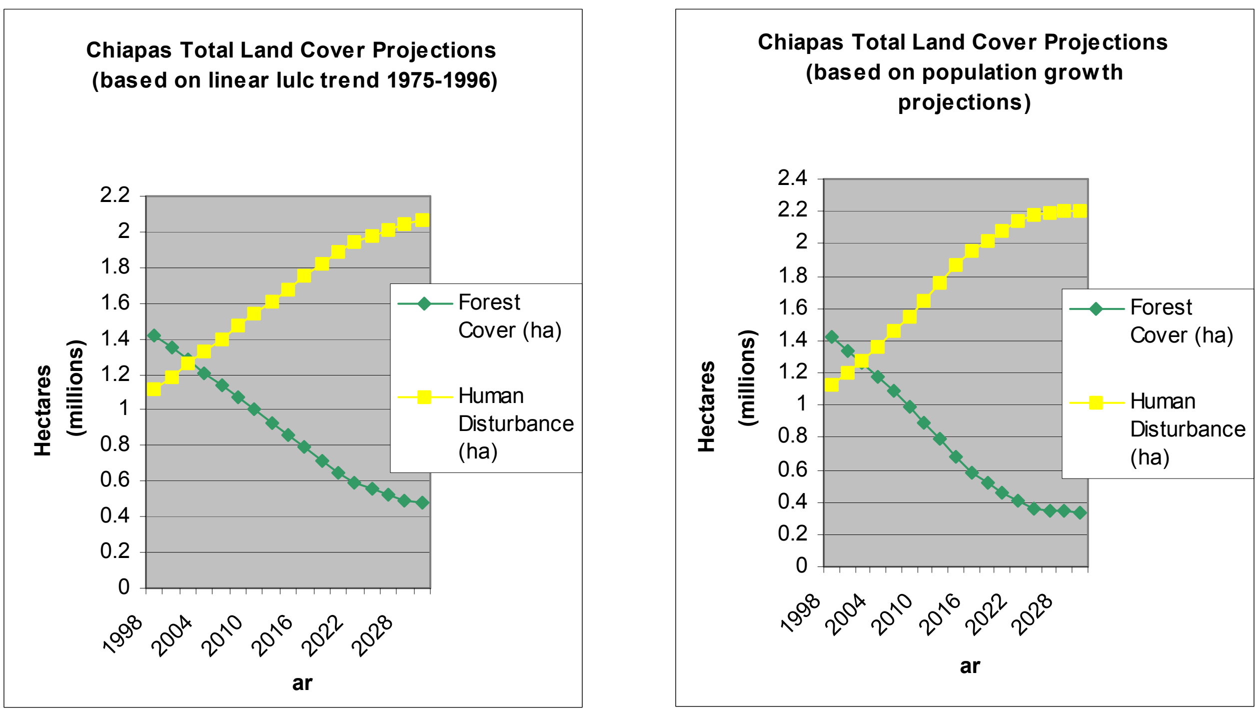
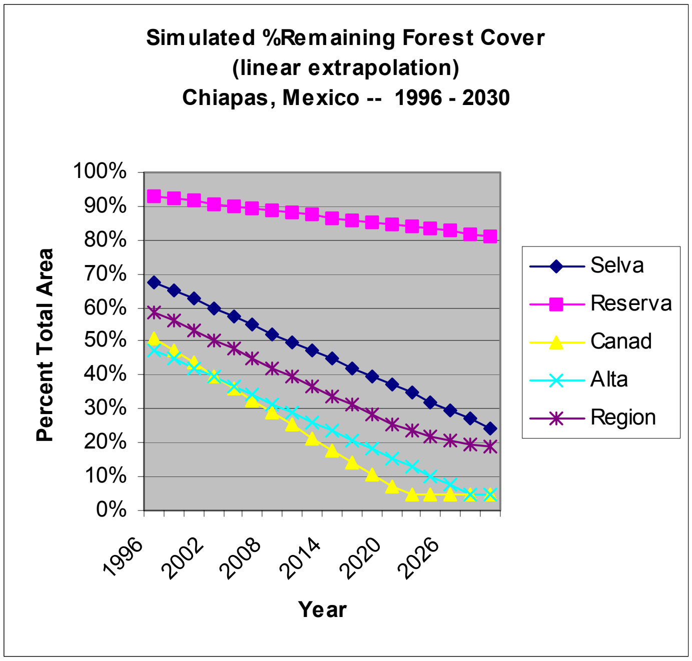
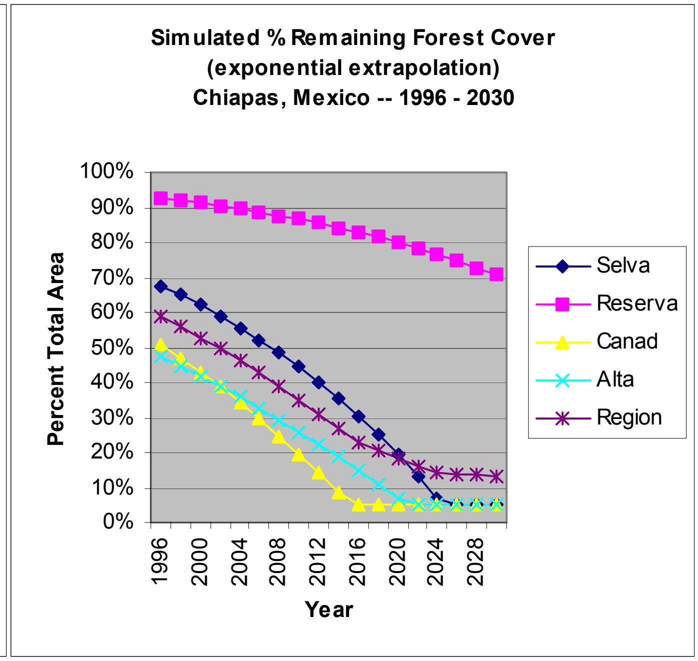


Figure 6. Simulated land use change using (a) a linear rate of deforestation; (b) an exponential rate.

Under a future rate tied to population projections almost 100,000 more hectares will be deforested. The most dramatic change is seen in the La Selva Lacandona region, where 95% of the total area is deforested by 2030, unlike in the linear trend projection where almost 25% of this region's forest remains in 2030 (Figure 7, a and b).



(a)

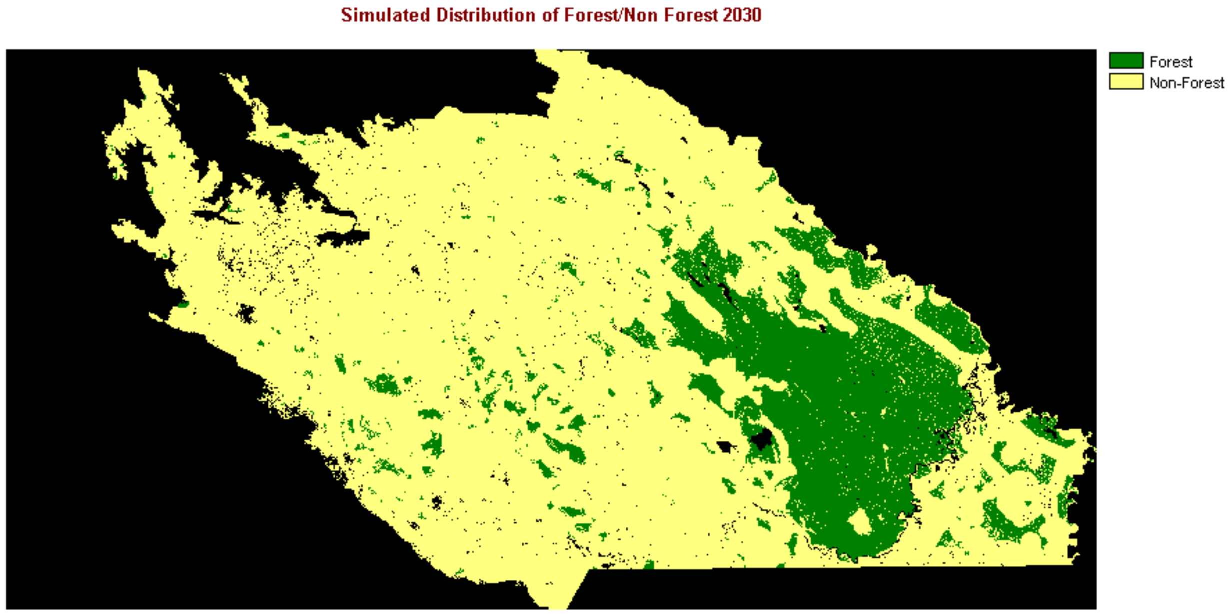


(b)

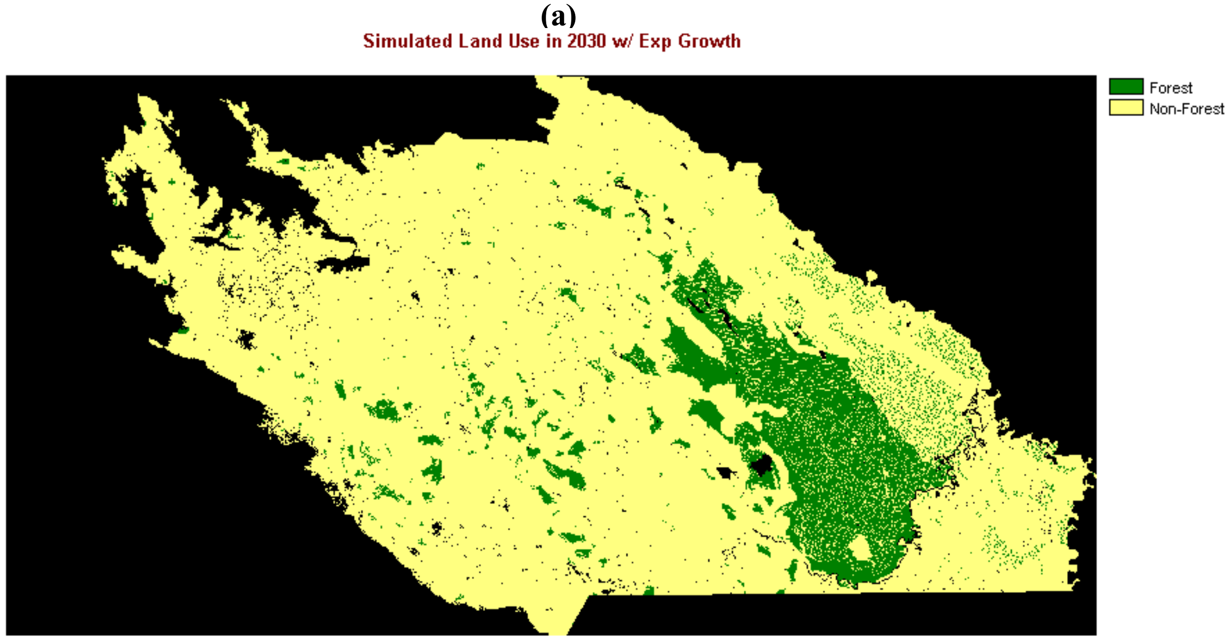
Figure 7. Projected % Area Forested over time – (a) using a linear trend; (b) using an exponential deforestation trend. Five % rule applies.

III. B. Distribution of LUC over Time

The two sets of maps, LAND**** and LEXP**** (where **** equals YEAR of simulation), can be viewed as two time-series within IDRISI. The first series (LAND) shows the loss of forest cover under the business-as-usual scenario. At the end of the simulation (Figure 8A), about 2.1 million hectares of land are deforested within all four regions. Under the second series (LEXP), the final deforestation figure is roughly 2.2 million hectares for all four regions (Figure 8B).



(a)



(b)

Figure 8. Year 2030 projected land cover simulation results, under (a) a linear deforestation rate and (b) exponential population projections.

III. C. Changes in Carbon Storage

All areas deforested were compared to the 1996 land cover map to derive carbon emissions. The general trend predicted by the model is the decrease in all forest types in all regions and the increase of non-forest (Figure 5). The main difference between the two scenarios is in the total amount of loss. Under the business-as-usual scenario, about 1 million hectares of forest are converted into non-forest between 1998 and 2030. Under the exponential scenario approximately 100 thousand more hectares are converted to non-forest, principally in the Selva Lacandona. The two scenarios should be viewed as the lower and upper limits of future LUC within the study region. We compared the areas that the model predicted would be cleared to the 1996 carbon map (Figure 7) provided by ECOSUR. The values for each vegetation type are listed in Table 5. Under the linear rate of growth the total carbon that would be lost without implementation of any carbon sequestering mechanisms is 175 million megatons, while under the exponential rate scenario that number is 208 million megatons (Figure7a and 7b). Most of the carbon loss comes from deforestation in the Selva Lacandona region – 63% in scenario one, and 69% in scenario two. Due to the overwhelming pressures caused by population growth, however, the scenario based on exponential population growth is probably the more realistic. What this means for carbon offset projects and the baselines on which they are built is this: without some sort of project, by 2030 between 63% and 75% (the more likely scenario) of the carbon stored in these forests in 1996 will be gone.

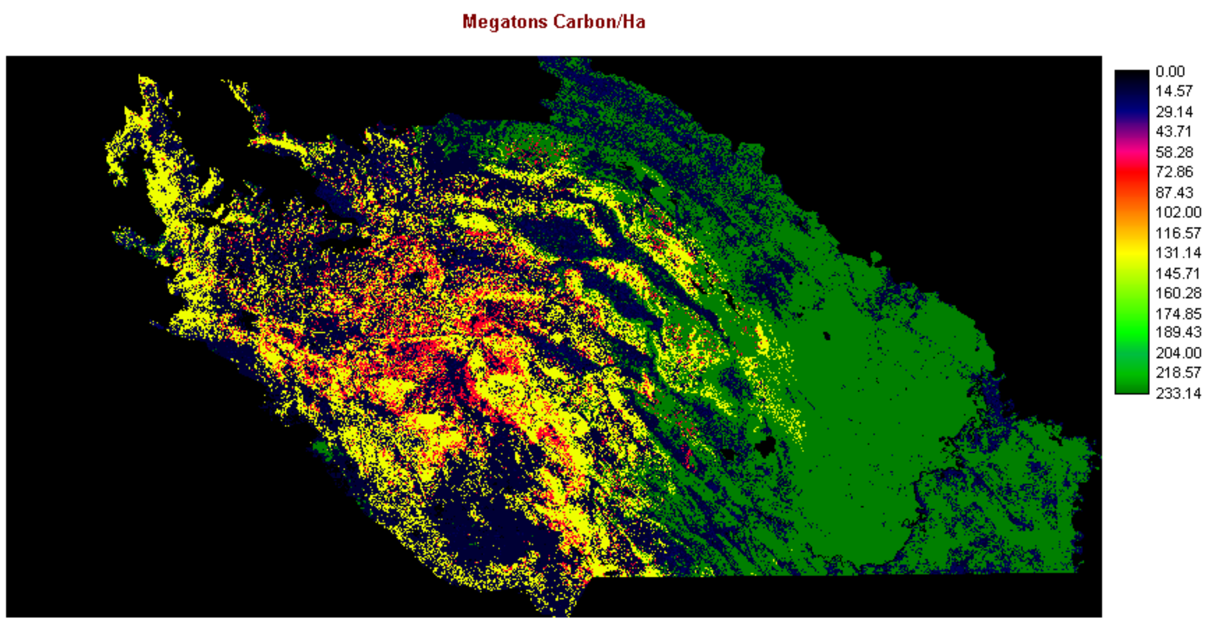
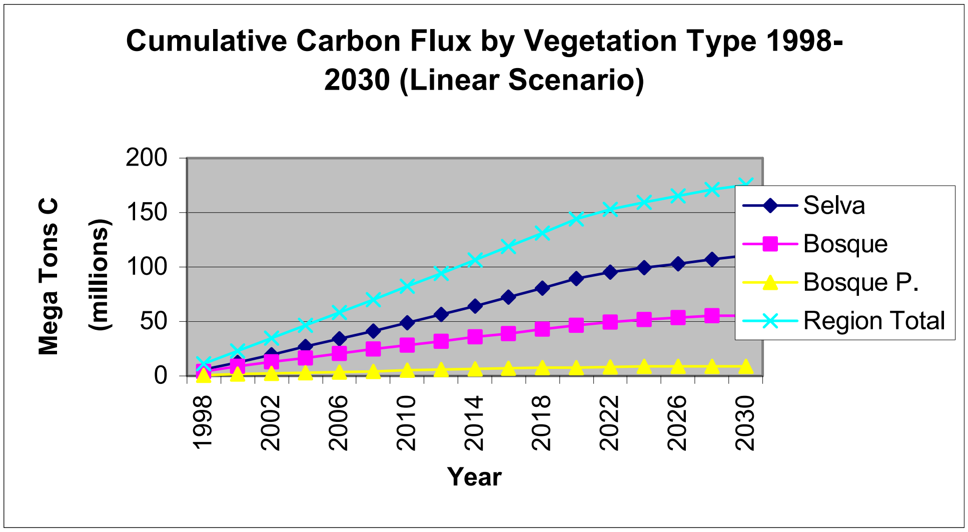


Figure 9. Carbon map based on 1996 vegetation categories.

Table 5. Carbon Content for 6 Land Cover types in the Chiapas Region.	
Vegetation Type	Mega tons/C/ha
Undisturbed Selva	233.14
Disturbed Selva	116.1
Undisturbed Bosque	135.4
Disturbed Bosque	69.1
Agriculture	12.1
Pasture	20.65



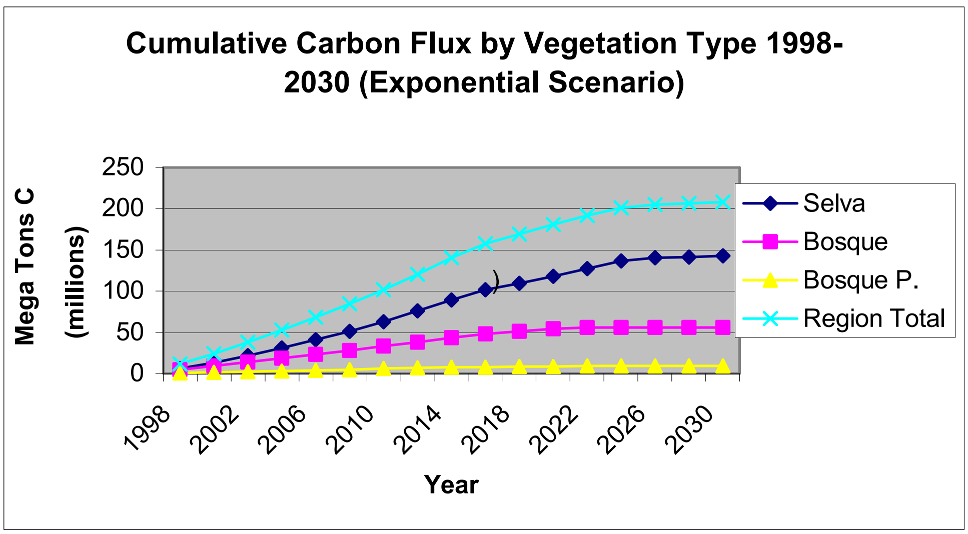


Figure 10. Cumulative without project carbon emissions projected (a) under a linear deforestation rate, and (b) under an exponential growth rate. The 5% limit applies.

IV. DISCUSSION

IV. A. Comparison of GEOMOD and ECOSUR

In order to better understand what our GEOMOD analysis is telling us about the Chiapas region, it should be useful to compare our techniques and results with those used by the ECOSUR group headed by Ben DeJong. Both the GEOMOD and the ECOSUR groups used methods to compare maps of past land-use patterns against other maps of potential spatial pattern drivers that may explain where people have tended to clear the forest. GEOMOD does this internally, validating results for each driver or combination of drivers against a land-use map from a later time period to see how well each factor or combination of factors allows us to project accurately land use at this second point in time. The first land-use map is called the calibration map and the second, the validation map. This is the first point at which the methodologies differ.

According to our reading of their publications and our conversations, the ECOSUR method does not test the ability of the factors that appear to be important in explaining land use at any given time to see if those factors can accurately project land-use changes into the future. Therefore, the ECOSUR team cannot validate their results in the same way that GEOMOD does. In other words the ECOSUR team uses a calibration map, but not a validation map. In some applications, when no validation map has been available, GEOMOD too, has used this methodology, but then GEOMOD will at least simulate from a completely forested landscape to the point in time of the calibration map in order to test the model's ability to recreate the calibration landscape. This is an important feature of our methodology because we feel that without some sort of validation we really cannot test our assumptions. It should be noted that although the three drivers selected by the ECOSUR method do show varying degrees of importance in explaining the 1992 land use pattern, GEOMOD found two other drivers to be significant, (1) the previous use of land (the best driver) was more important than any of the others tested, and (2) distance from previously deforested land, which also gave us better results than the level of marginalization. This illustrates the second point at which our two methodologies differ as well as the power of GEOMOD to evaluate and test numerous drivers until both the best individual and the best combination of drivers are found.

Next, based on their particular analysis of the importance of each spatial driver both models then assign a "weight" to each grid cell in the landscape. This weight in both cases, if we have understood correctly, is basically the percent of all cells in the map of a given class (let's say within 300 meters from a roadway) that were already deforested in the calibration land-use map. GEOMOD sums all driver weights for each cell. The ECOSUR method creates a matrix of the three drivers (density of population engaged in working the land; the marginalization index; and distance from roads) and the three classes within each driver and assigns this percentage or weight to each cell based on its class within each driver. GEOMOD then simulates the future in time steps, based on its analysis of the appropriate area of change. The ECOSUR method does not simulate land-use change. Rather it predicts future landscape carbon values. Every landscape cell's current carbon value is decreased according to the percentage in the matrix that corresponds to the cells distance from roads, agricultural population density and marginalization level.

With respect to projections of a future landscape, the two methodologies differ greatly in that the ECOSUR methodology, as far as we can tell, does not attempt to predict where additional deforestation will occur, but instead adjusts the future landscape carbon values based on the 3 by 3 matrix percentages. This means that in the future projected landscape in the ECOSUR evaluation any cells that had no deforestation in the calibration period will have no deforestation in a future time period because within the matrix their percentage would be zero. Thus the ECOSUR method does not show any additional deforestation (or rather reduced carbon values) occurring on lands that would have low values in their 3 by 3 matrix, whereas GEOMOD must "eat" into those lands as the best land (most vulnerable according to our analysis) is used up. We find the approach used by GEOMOD to be a more realistic representation of how humans actually use land.

Because the ECOSUR method is static, we caution its use for the variety of reasons discussed above. In addition it does not account for rate of change. In GEOMOD the simulation of the distribution of land use over time is dynamic in that it can project a rate of change and captures the pattern in a more realistic fashion.

IV. B. Carbon Issues

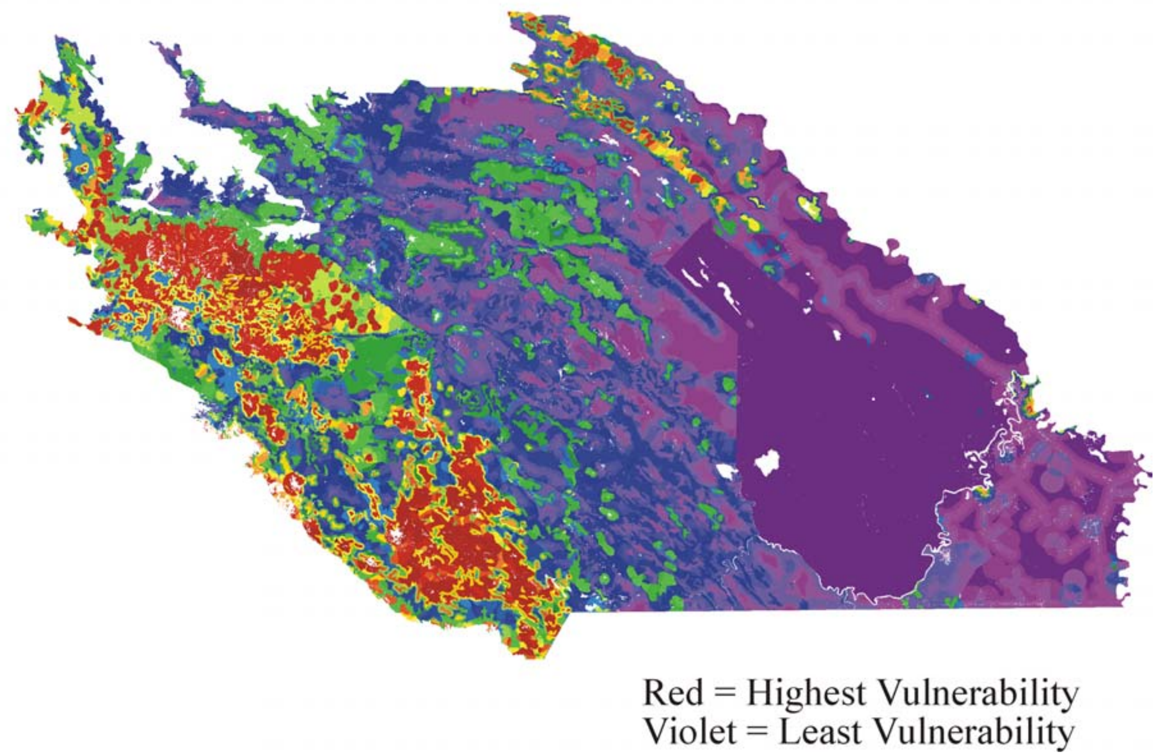
GEOMOD predicts a carbon future by referencing a vegetation map for which carbon content has been derived and calculating for each simulation period the amount lost in that period to deforestation. The values for carbon for the Chiapas region are reported in two places: first the values of the highland (Alta) are reported in Ben DeJong's thesis (2000). The carbon values for the Selva are reported in the DeJong et al. (2000). For the ECOSUR analysis (according to presentation by Miguel Angel) the numbers for the 6 LULC types were applied. We have used these same numbers.

It appears that these numbers represent only general estimate of the true distribution of carbon versus vegetation types. Comparison of these numbers with the values given in DeJong (2000) and in the DeJong et al. (2000) show that there are large differences between different land use/land cover types and between the same land use/land cover types from different regions. In order to use GEOMOD results to estimate the carbon baseline accurately we would need to have the ECOSUR team's original maps of vegetation and land use.

Given access to these additional pieces of data however, it is expected that the estimated carbon losses due to GEOMOD's simulation of the distribution of additional areas of deforestation in the future will be wildly different from that obtained by the ECOSUR methodology. Based on the past and potential future rates and distribution of deforestation GEOMOD predicts that as much as 95% of all forest areas in each region, and potentially more than 95% of all the carbon originally found in these forests will be lost without some sort of protection and active management. In order to estimate the exact amount that would be lost, however, we would need to incorporate the results from GEOMOD with the original highly detailed carbon map that we believe ECOSUR has created.

This assumption is based on the widely divergent views of the two groups concerning which areas, and consequently which stocks of stored carbon are at risk. In the ECOSUR methodology, seemingly, those stocks of carbon that were most depleted in the period between 1975 and 1996 were also considered to be most at risk in the future. Logically, there is nothing wrong with this idea and it has a great deal of backing in the literature detailing how people do tend to use disturbed lands first (del Mar, et al. 2001). Therefore, those lands that were disturbed and had already lost carbon are treated in GEOMD as ‘at risk.’ Where the two methodologies seem to differ the most is in the fact that GEOMOD predicts that additional areas will be deforested based upon demand, and it looks for the next most likely piece of real estate to fall to the axe. Thus areas that may be shown in either the ECOSUR methodology as not ‘at risk’ or in GEOMOD’s Vulnerability Map as not ‘at risk, may in fact become ‘at risk’ due to mounting pressure for land.

Map of Vulnerability Based on Analysis of 1975 LU



In FIGURE 1., strong linearity may be observed which correspond to the political borders of each region. Because the rate of LUC was significantly different within each region, the predicted values of vulnerability are different as well. But the map clearly shows that all areas within all regions share some vulnerability. Then, based upon other rules such as contiguity with and proximity to previous land use, GEOMOD is capable of predicting the future distribution of LUC within this map of vulnerability. So, the vulnerability map shows where future LUC is likely to occur, and GEOMOD tries to simulate those changes. Ideally, if we had just one more map of LUC for some point past 1996, we would again be able to validate GEOMOD for the period up to that point in time, and then re-calibrate the model and simulate again into the future.

Based upon both scenarios of future LUC however, it is clear that more precise data on LUC may not be necessary, if in fact the vast majority of land will be cleared. Instead what would be most useful would be the kind of detailed carbon storage map and carbon release information that the ECOSUR team has developed.

One last comparison with the two approaches therefore may be instructive. The ECOSUR model is highly detailed concerning the fate of carbon, but to our knowledge is not a true spatial model, although it does use spatial data. The ECOSUR model is "static" because (1) in the model, grid cells do not interact and (2) future changes in the distribution of land use are not simulated. In comparison, GEOMOD is comparatively "static" as regards carbon. What GEOMOD does is simulate the distribution of LUC over time. It is then up to the operator to convert changes in the extent of land use into changes in carbon stocks. Perhaps, the best overall approach therefore might be some combination of the two methodologies.

V. CONCLUSIONS

Given the desire of all parties involved to generate the most scientifically defensible estimate of the "without" project estimate, it would seem that neither of the separate methodologies employed by ECOSUR or by GMS can fully explain the relationship between land-use change and carbon exchange in the study region. However, if the results from GEOMOD are correct, the over-riding concern in the region will not necessarily be the precise fate of the carbon that is lost once deforestation takes place, but rather, the total amount of forest that will be lost.

Therefore, while it is clear that additional data from the ECOSUR group could help the GMS group develop a better description of the fate of carbon, even greater gains can be made by making the ECOSUR methodology more spatially explicit. If for example, the ECOSUR group could just incorporate the predicted extent and distribution of future land-use change into its methodology, their results, logically, should be greatly improved. We believe that perhaps the best way to do this would be to combine their methods with GEOMOD.

VI. Literature Cited

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APPENDIX

Table 1. Total Area to be deforested based on Exponential Population Growth Model Results

YEAR	SELVA	RESERVA	CANAD	ALTA
1996	373311	294619	490944	333618
1997	366069.	293500.	472596.	324109.
1998	358571.	292342.	453796.	314421.
1999	350810.	291145.	434533.	304551.
2000	342776.	289907.	414797.	294496.
2001	334458.	288627.	394576.	284253.
2002	325848.	287302.	373857.	273817.
2003	316935.	285932.	352628.	263185.
2004	307708.	284515.	330878.	252353.
2005	298156.	283050.	308592.	241318.
2006	288268.	281535.	285758.	230076.
2007	278032.	279967.	262362.	218623.
2008	267435.	278346.	238391.	206955.
2009	256465.	276669.	213831.	195068.
2010	245109.	274935.	188666.	182957.
2011	233354.	273141.	162882.	170620.
2012	221184.	271286.	136464.	158050.
2013	208586.	269367.	109396.	145245.
2014	195545.	267382.	81662.	132199.
2015	182044.	265330.	53246.	118908.
2016	168068.	263207.	24132.	105368.
2017	153600.	261011.	-5699.	91574.
2018	138623.	258740.	-36264.	77520.
2019	123118.	256391.	-67581.	63203.
2020	107068.	253962.	-99668.	48617.
2021	90452.	251449.	-132544.	33757.
2022	73252.	248850.	-166229.	18618.
2023	55445.	246163.	-200742.	3195.
2024	37013.	243383.	-236104.	-12517.
2025	17931.	240508.	-272336.	-28525.
2026	-1823.	237534.	-309460.	-44833.
2027	-22272.	234458.	-347496.	-61447.
2028	-43441.	231277.	-386469.	-78374.
2029	-65355.	227987.	-426399.	-95618.
2030	-88041.	224584.	-467312.	-113185.