Deforestation in Santa Cruz de la Sierra, Bolivia
by Stacie Wolny

Introduction

The Department of Santa Cruz, Brazil is experiencing one of the highest rates of deforestation in the world. To the east of its capital city Santa Cruz de la Sierra, agriculture has very rapidly degraded the largest area of contiguous dry tropical forest remaining in the world, causing conservationists and ecologists to put it among their highest priorities for preservation. This project compares Landsat images of the Santa Cruz region from 1987 and 2000 to assess the change in land use over time.

Background

Santa Cruz de la Sierra is the largest city in Bolivia, situated at the base of the Andes in the semi-tropical lowlands of the Amazon Basin, surrounded by lush forest. Semi-deciduous tropical forest (or dry tropical forest) had been widespread over central South America, but human use and weather pattern changes have whittled it down until mostly fragments remain, except for the large expanse around Santa Cruz. These dry forests (experiencing a season without rain, unlike rainforests) are unique ecosystems with high rates of general biodiversity, housing endangered animals like the jaguar and giant anteater, as well as being the specific center of diversity for important food crops which originated there like peanuts, runner beans and tomatoes.

Until the 1950s, Santa Cruz was rather isolated and had a relatively small population. Then Bolivian government programs began providing cheap land to highlanders willing to colonize and work the surrounding lowlands, which began an influx of migrants that has continued to this day. Soybean production took hold in its fertile soil as a cash crop in the 1970s on a small scale, increasing as people from the Andean high planes were resettled around Santa Cruz. In 1990 the World Bank began its Tierras Baja project there, a large-scale agricultural development program that caused accelerating deforestation as increasing numbers of people cleared land to make money growing crops for export, particularly soybeans. Timber harvesting increased as loggers cut roads deeper into the forest, paving the way for more new settlers. Annual rates of forest clearing went from 20 km² in 1990 to over 100 km² by 1998 and have remained almost as high.

Methods

Two sets of GeoTIFF images, bands 1-5 and 7, were downloaded from the University of Maryland's Global Land Cover Facility website, one set from 5/26/1987 and the other from 8/1/2000 (the latest date for which there was data.) These were both imported into Idrisi Andes, and initial unsupervised classifications were done, creating Isoclusts with 10 clusters. This proved to be too few classes for separating agriculture well from forests and grasslands, so 15-cluster Isoclusts were created, which did appear to provide much better groupings.

In order to determine the land cover type of each class, several other methods of visualization proved useful. Since general vegetation types were being emphasized, after some trials looking at bands 4 and 3 individually and in ratios, an NDVI was generated using Idrisi's VEGINDEX function to show vegetation density. This was the most helpful for seeing differences in forest densities and mature versus young agriculture as well as locations that appeared to be fallow agriculture or bare ground. Supporting the NDVI was a composite of bands 1, 2 and 3, which gave a realistic (somewhat – it was suspiciously blue) visual interpretation for checking features like lakes and bare ground. A 3x3 Mean Filter image was also useful when looking at details, as it seemed to remove some noise and more clearly define the features. Finally, Google Earth was used as a sort of virtual ground truthing for locations of forest vs agriculture, bare ground etc, realizing that seasonal differences, among many other things, made this only of limited general use.

Initial merging of similar land cover types was then done, creating 7 main classes: Dense Dry Forest/Riverine Forest, Dry Forest, Grassland/Scrub, Mature Agriculture, Young/Fallow Agriculture and Bare Ground/Fallow Agriculture.
However, 15 clusters did not group water features well. A river was grouped with bare ground, which was understandable given that siltation was likely to be present. Lakes were grouped together in 1987 and separated in 2000, with some classified together and one other grouped with forest. Looking more closely, it appeared that there were significant changes in the sizes of the lakes, which were larger in May, 1987 (at the end of the rainy season) and smaller in August, 2000 (near the end of the dry season), with some lakes being completely dry in the 2000 image. The differences in grouping could have been due to corresponding differences in lake level and turbidity from rain inflow.

Based on this, (and frustrated by trying to do a manual classification to break them out more properly), I decided to see if 25 clusters would provide a better grouping. Indeed it did group water features better, while keeping the land features' clusters close to those broken out in the 15-cluster Isoclust, so not much additional work was required to use the additional clusters. Subsequent regrouping of the 25 clusters added one class, Water, for a total of 8, and did help slightly refine the previous young/fallow and bare ground/fallow groupings.

Finally, the images' 8 clusters were renamed and recolored. Forest, scrub and water cluster colors were chosen to be somewhat realistic, while agricultural clusters were given false colors to highlight agriculture differences as well as emphasize how dramatically agriculture has displaced forest.

Results

After analysis, regrouping and recoloring two final images were produced:

![Santa Cruz Landcover – 5/26/1987](image1)

![Santa Cruz Landcover – 8/1/2000](image2)

From these, Idrisi's AREA function was used to calculate the areas of each class, which were summed and grouped by agricultural use versus wilderness:

<table>
<thead>
<tr>
<th>Class</th>
<th>1987</th>
<th>2000</th>
<th>Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forest/Scrub/Water</td>
<td>30560</td>
<td>21226</td>
<td>-9334 km²</td>
</tr>
<tr>
<td>Agriculture</td>
<td>2381</td>
<td>11686</td>
<td>+9305 km²</td>
</tr>
</tbody>
</table>

These sums did not change exactly comparably, which I attribute to differences in how grassland/scrub and fallow agriculture were classified between the two dates, as they appeared to be just slightly mixed in the 25-cluster classifications. Additionally, there could be changes in crop cover based on crop type and growing season and changes in semi-deciduous forest foliage cover in the beginning (May) versus end (August) of the dry season, which could alter the agriculture/grassland groupings.
Conclusions

From this analysis, both visually and numerically, it is apparent that significant amounts of dry tropical forest east of Santa Cruz de la Sierra Bolivia have been transformed into agriculture over the past 13 years.

Fortunately, satellite imagery provides hard visual evidence of such man-made ecological destruction, and the very Landsat images used in this project have made Santa Cruz a poster child for Amazonian deforestation and are beginning to spark positive change. Recently, much effort has been put into enlightening international corporate soybean purchases and implementing sustainable agricultural and forestry practices in the area, which seems to be finally causing a slight decrease in the rate of deforestation, and has lead to Santa Cruz now having the majority of Bolivia's certified sustainably-harvested forests.

There are many possibilities for improvements and future work with these maps, particularly as a tool for monitoring further change and possible recovery of the area. It would be interesting to do further analysis to separate out different types of crops grown and more precisely differentiate between forest/scrub land types. Adding layers of temperature and moisture levels over time could show correlations between loss of forest and more extreme daytime/nighttime temperature fluctuations (which has been observed there), and possible related changes in the overall forest/scrub ratio, density and rate of deciduousness. More precise soil analysis may show trends in soil depth, composition and moisture retention accompanying changing agricultural practices. There is so much more to learn.