# Non-Frontier Deforestation in the Eastern Amazon


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### Introduction and Rationale

- Most attention regarding deforestation has been focused on the deforestation frontier
- However, areas that have been settled by humans for decades or centuries are also still undergoing land-use change, including degradation of remaining forests
- Here we use Landsat imagery to quantify changes in forest cover from 1984 to 2002 in a 8000 km² study area east of Belém, which was first settled over a century ago.

**Figure 1. Study area in eastern Pará, Brazil.**


### Data & Methods

*Satellite Data:*

Landsat TM: Jul 27, '84, Jun 21, '94, & Jul 13, '99

Landsat ETM: Aug 3, '01, & Sep 7, '02

- Imagery Georectification of 5 dates to a common map projection
- Imagery calibration to reflectivity via the COST Model (Chavez 1996)
- Field work with GPS data as the primary source for classification and validation
- Some limited IKONOS data also used for validation
- Supervised classification using ERDAS Imagine Software
- Map creation and overlays using ARCMap 9.3

*Biomass Data:*

Published aboveground biomass estimates (Mg ha$^{-1}$), were used for each forest cover class (mean ± one standard deviation):

- Young secondary: 26 ± 22
- Intermediate secondary: 67 ± 19
- Advanced secondary: 123 ± 4
- Mature: 251 ± 72

### Results and Discussion

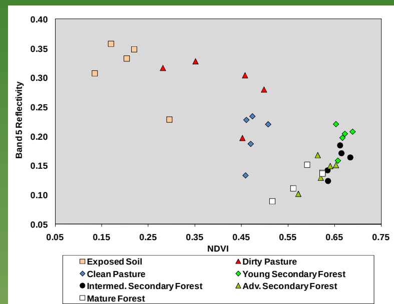


**Figure 2. The separation of land cover classes plotted on a 2-D space of Normalized Difference Vegetation Index (NDVI) and band 5 reflectivity. Each point represents the mean values for a land cover class for one of the five years of images analyzed.**

- Variation among scenes, likely due to differing amounts of rainfall in months preceding the image acquisition, causes some overlap among the clusters of classes, especially for the forest classes.
- Within a single scene, however, the younger forests consistently have lower NDVI and higher band 5 reflectance than do older forests.
- A decrease in band 5 reflectance with forest age has been attributed to increases in vegetation moisture and increased trapping of mid-infrared radiation as the structurally complexity of the canopy develops with forest age.
- Bare soil, dirty pastures (those with woody shrubs), and clean pastures (those with little or no woody vegetation) have progressively higher band 5 reflectances and lower NDVI values.

Table 1. Percent area of the 8000 km$^2$ study region by land cover class for five dates of Landsat data.

| Class | 1984 | 1994 | 1999 | 2001 | 2002 |
|---|---|---|---|---|---|
| Mature Forest | 21.3 | 6.6 | 5.2 | 5.9 | 8.2 |
| Advanced Secondary Forest | 8.4 | 19.1 | 22.1 | 20.0 | 21.1 |
| Intermediate Secondary Forest | 11.2 | 38.4 | 24.9 | 22.3 | 17.5 |
| Young Secondary Forest | 34.2 | 17.5 | 24.3 | 25.0 | 14.8 |
| Dirty Pasture | 9.2 | 8.7 | 10.6 | 5.3 | 7.1 |
| Clean Pasture | 8.1 | 7.3 | 10.0 | 20.3 | 29.8 |
| Soil | 2.8 | 1.2 | 1.5 | 0.9 | 0.6 |
| Water | 2.1 | 0.2 | 0.5 | 0.4 | 0.2 |
| Cloud | 2.7 | 0.4 | 0.5 | 0.0 | 0.2 |
| Shadow | 0.0 | 0.6 | 0.5 | 0.0 | 0.5 |

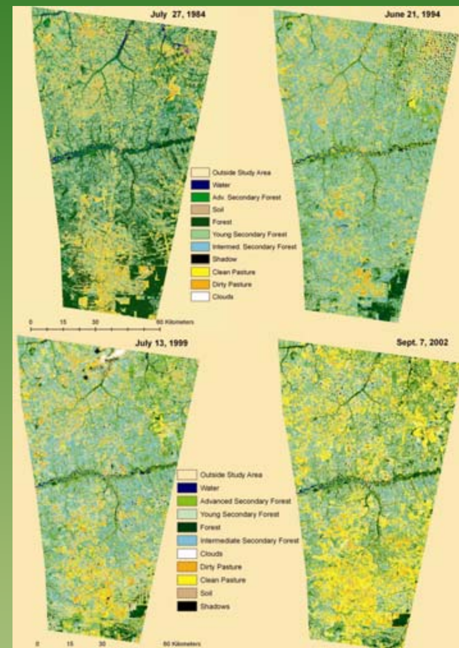


**Figure 3. False color images showing classifications of cover types (2001 image, not shown, is similar to the 2002 image).**

- Large patches of mature forest remained in the southern part of the image in 1984, but were mostly cleared by 1994.
- The remaining areas classified as mature forest mostly occur in margins of streams and rivers, locally known as *igapó* forests.
- Between 1999 and 2002, a significant expansion of clean pasture (yellow) is apparent.

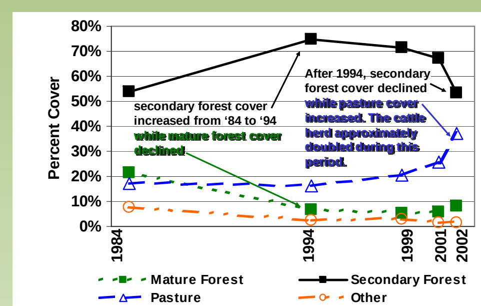


**Figure 4. Temporal change in the percent cover of four land cover classes, aggregated from the data presented in Table 1.**

- The area of mature forest declined from 21% of the region in 1984 to about 5-8% at the end of the study.
- As mature forest cover declined from 1984 to 1994, a commensurate increase in secondary forest cover occurred.
- However, secondary forest cover then decreased after 1994, with a proportionate increase in pasture cover.

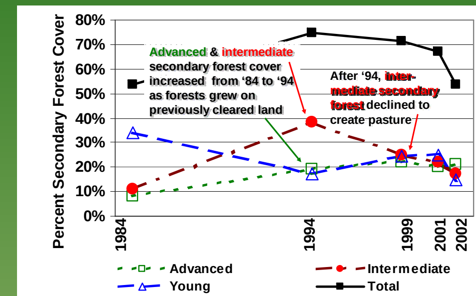


**Figure 5. Percent cover of 3 successional stages of secondary forest.**

- The large area of young forest in 1984 became mostly intermediate-aged forest by 1994. Apparently, the demand for agricultural land was not so high to require that fallow fields be re-cleared during this period.
- After 1994, however, the intermediate-aged secondary forests declined as the area of pasture increased. Total pasture cover increased from 17% to about 37% of the study area, with clean pasture being six times more common than dirty pasture in 2002.

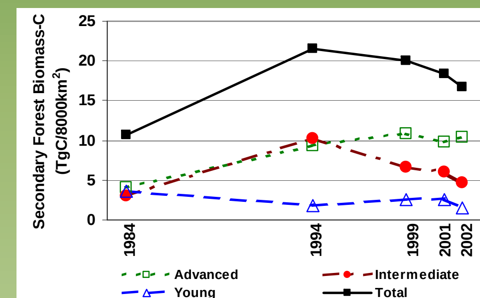


**Figure 6. Estimated secondary forest biomass carbon by successional stage class for the entire 8000 km² study area.**

- Secondary forest biomass increased from 1984 to 1994 as the area increased and as secondary forests aged.
- This pattern was reversed after 1994. From 1999 to 2002, the 8000 km² area was losing about 1.0 Tg C yr$^{-1}$, which is equivalent to about 1.3 Mg C ha$^{-1}$ yr$^{-1}$ averaged over the entire 8000 km² area.
- The secondary forest biomass in 2002 was about equal to that present in 1984, but mature forest cover decreased from about 21% to about 8% during this period (Fig. 4), causing a net loss of 13 Tg C from aboveground forest biomass for the 8000 km² area, which is equivalent to an average loss of 0.9 Mg C ha$^{-1}$ yr$^{-1}$.

### Conclusions

- From 1984 to 1994, land cover change was mostly from mature forest to secondary forest; more recent changes (1994-2002) were mostly from secondary forest to pasture.
- The average net rate of carbon loss over the study period was 0.9 Mg C ha$^{-1}$ yr$^{-1}$, which is similar to many estimates of C sequestration rates in mature Amazonian forests.
- Remnant mature forests and extensive secondary forests are still being cleared in this region. Although no longer receiving the same attention as the deforestation frontier, this region of historic deforestation is still losing substantial amounts of forest biomass carbon to the atmosphere.


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