Tracking deforestation and tree plantation expansion in a Costa Rican biological corridor using a Landsat time series

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Abstract

We evaluated forest policies and programs to reestablish connectivity in a fragmented tropical landscape spanning approximately 2500 km^2: the San Juan-La Selva Biological Corridor (SJLSBC) in northern Costa Rica. National forest conservation programs have concentrated payments for environmental services (PES) within corridors to establish tree plantations and protect forests on private land; the corridor program was instituted in 1996 as part of a Forest Law that also banned deforestation country-wide[1]. Despite the innovative nature of this program, agricultural pressures on the SJLSBC may have impeded its implementation.

To effectively and efficiently monitor forest protection laws and conservation incentives, new remote sensing-based methods are needed that can overcome difficulties in distinguishing between tropical tree plantations, mature forests, and forest regrowth using low-cost moderate- (10-100 m) to coarse-resolution (100-300 m) satellite sensors[2]. The objective of this study was to accurately map changes in the area of these three forest types and agriculture in northern Costa Rica using Landsat imagery spanning a 25 year period (1986-2011). We used a combined hierarchical approach that integrates temporal image-object segmentation and machine-learning classification techniques to track forest cover change and distinguish between spectrally-similar forest types.

Results indicate that, during the 15 years since its creation, the deforestation ban has been effective in protecting mature lowland forests. The area of secondary forest declined however, indicating that agricultural pressures on easily-clearable land are increasing. Tree plantations expanded rapidly over the time period analyzed, although the rate of increase has slowed. Agricultural intensification was notable during the period of study; pineapple cultivation expanded dramatically into former pastures and threatens to bisect the corridor zone by expanding down major river valleys. Although the SJLSBC program and national deforestation ban have protected mature forest and promoted tree plantation establishment, the expansion of intensive agriculture and long-term decline in secondary forest may lead to a semi- permanent loss of forest connectivity in this developing region.

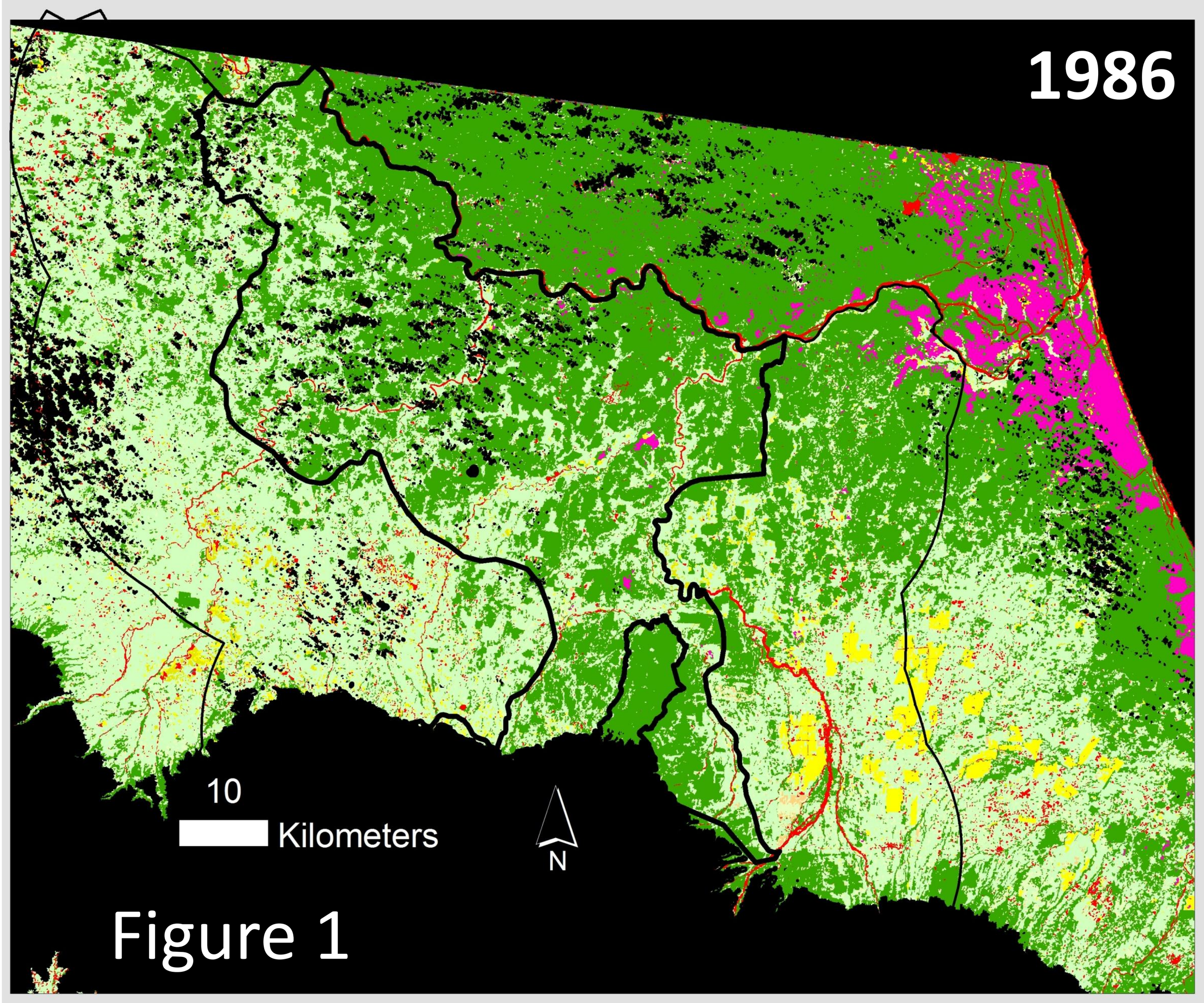

Figure 1

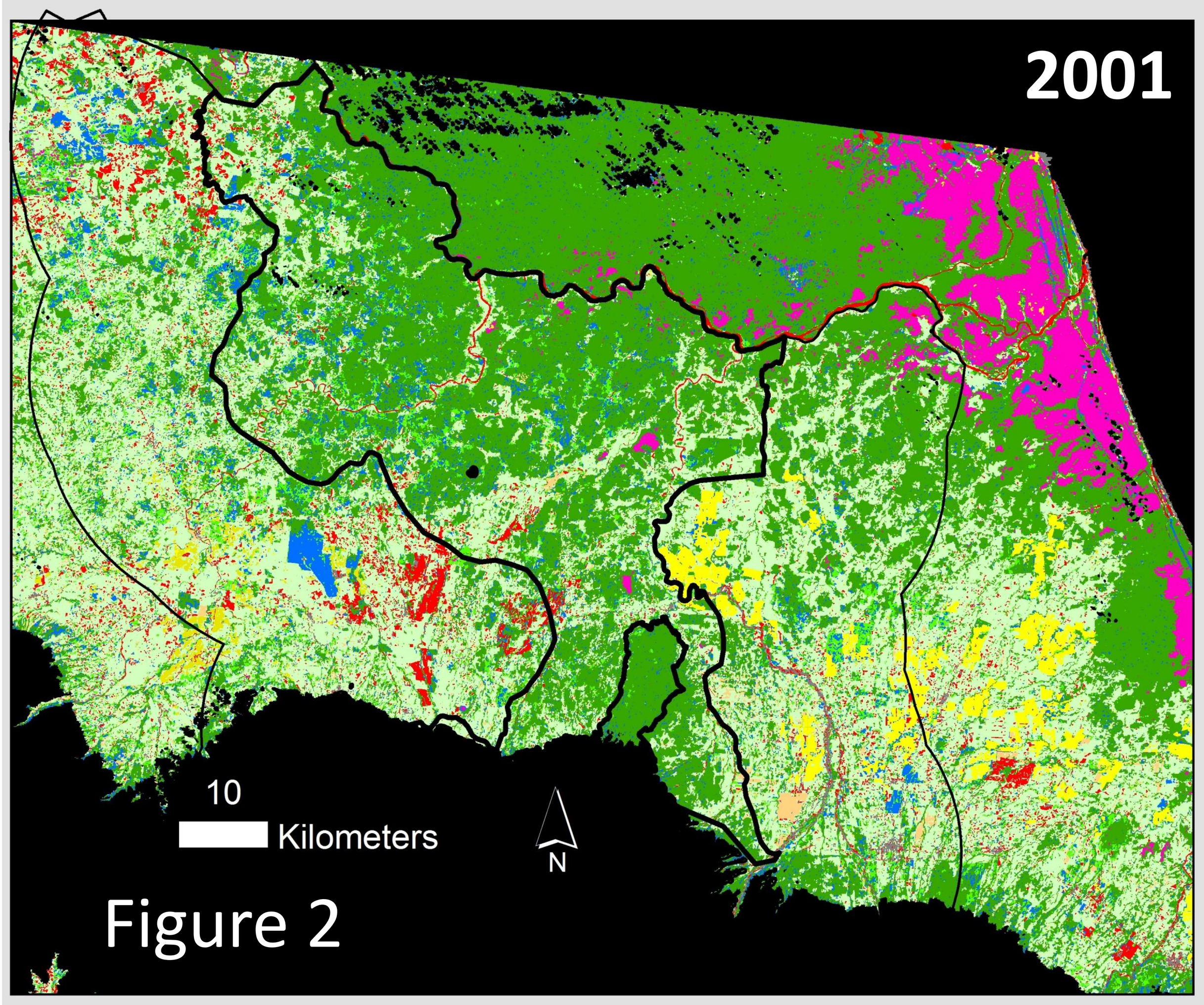

Figure 2

Legend

- Secondary forest
- Urban
- Swamp forest
- Tree Plantation
- Pasture
- Lowland forest
- Pina/Bare soil
- Palmito
- Sugarcane
- Banana
- Masked clouds

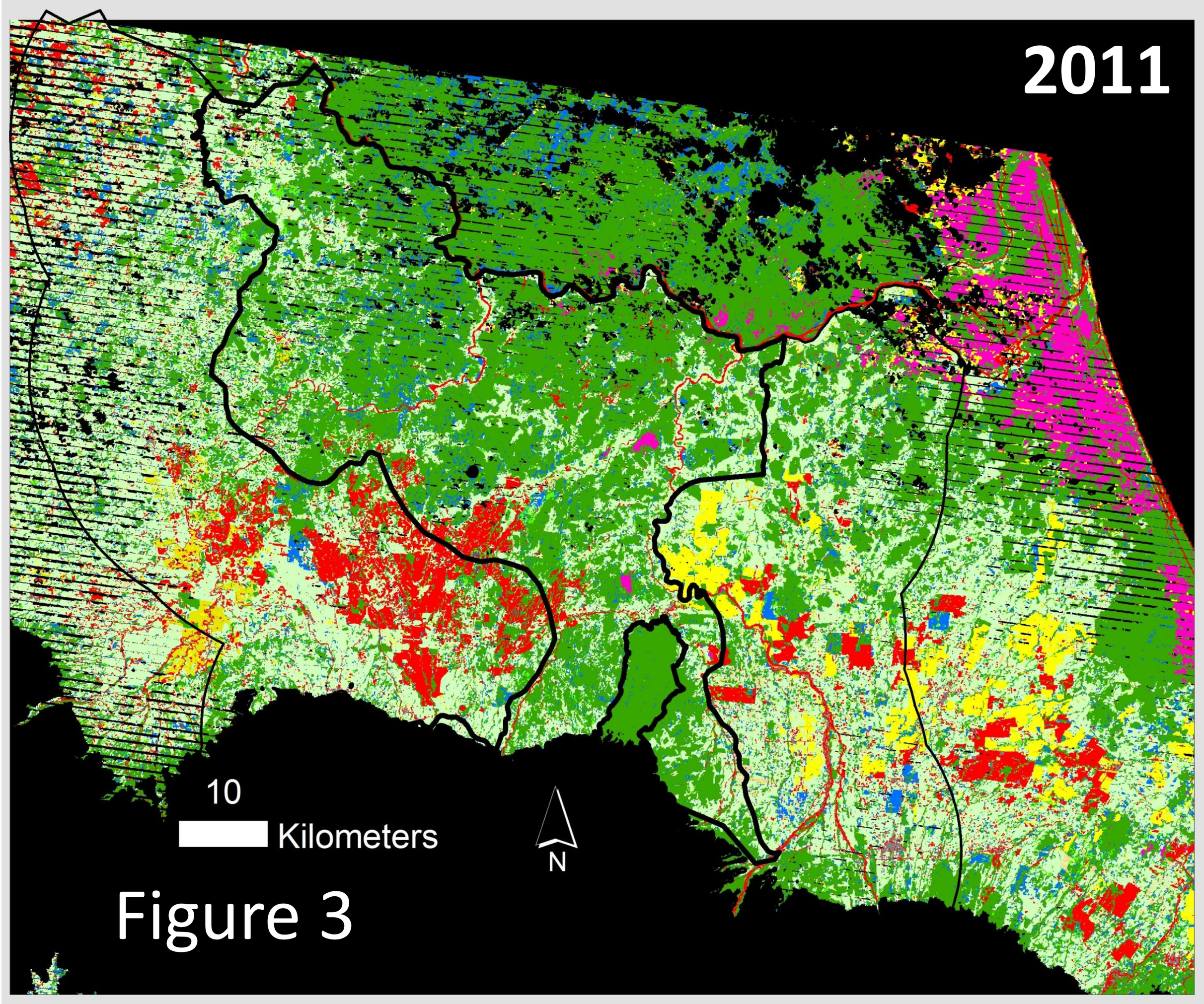

Figure 3

Land cover maps derived from Landsat images. The heavy black line indicates the SJLS Biological Corridor below 500 m elevation, and the light black lines indicate an informal 20 km buffer for analysis.

Figure 1: Land cover class accuracy assessed with forest/nonforest testing data derived from aerial imagery. Overall map accuracy: 90%. Best class accuracy: Forest (88% User/95% Prod.). Worst: Open (91% User/81% Prod.).

Figure 2: Class accuracy assessed with 2001 field testing data. Overall map accuracy: 80%. Best class accuracy: Banana (87% User/93% Prod.), Urban (89% User/89% Prod.). Worst: Palmito (61% User/74% Prod.), Tree plantations (65% User/77% Prod.).

Figure 3: Class accuracy assessed with 2011 field testing data. Overall map accuracy: 87%. Best class accuracy: Banana (91% User/90% Prod.), Pina/Bare soil (92% User/93% Prod.). Worst: Palmito (55% User/74% Prod.), Tree plantation (72% User/83% Prod.).

Detailed Methods

We classified three dates (1986, 2001, 2011) of multispectral Landsat TM and ETM+ imagery (30 m resolution) for northern Costa Rica. Landsat images were collected in the winter dry season (Dec to March), geometrically corrected to an L7 image, atmospherically corrected using Ledaps , radiometrically corrected using the MAD algorithm, and mosaicked to mask clouds and eliminate line errors (images from 1986/1987, 2001, and 2010/2011/2012). An object–oriented algorithm from Ecognition software was used to segment this image stack., and classification was performed on data derived from the resulting objects.

Using the Random Forests (RF) classifier and training data from 2005 and 2011 field campaigns and 1986/92 aerial photography, we classified each single-date Landsat imagery to nine land cover classes (Figures 1-3). All training and testing ROIs were derived from field data points and assigned to their respective object data for classification. The tenth class, Secondary Forest, was derived by mapping the regrowth of mature lowland forest between time periods. We compared land cover change across time, with the explicit assumption that tree plantation and secondary forests were absent in 1986. This assumption arises from the rarity of tree plantations in early aerial photos, and current challenges in mapping secondary forests at the start of the time series. Further analysis will relax this assumption. All classification analyses were conducted using Envi/IDL 4.8 and R 2.13.1.

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Literature Cited

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Results and Conclusions

In this ongoing analysis of the 1986-2011 Landsat image stack, there are several results so far:

- The deforestation ban in 1996 appears to have been effective in reducing deforestation.
- The pulse of reforestation and forest regrowth that followed PES establishment has halted or declined, partially agreeing with the 2001 results of Morse et al. [1]
- Land cover change in the analysis buffers has been much more dynamic than inside the Corridor, with expansion of intensive agriculture and some forest loss.
- Continuing work will evaluate forest change and improve mapping accuracy of tree plantation and palmito.

Figure 4

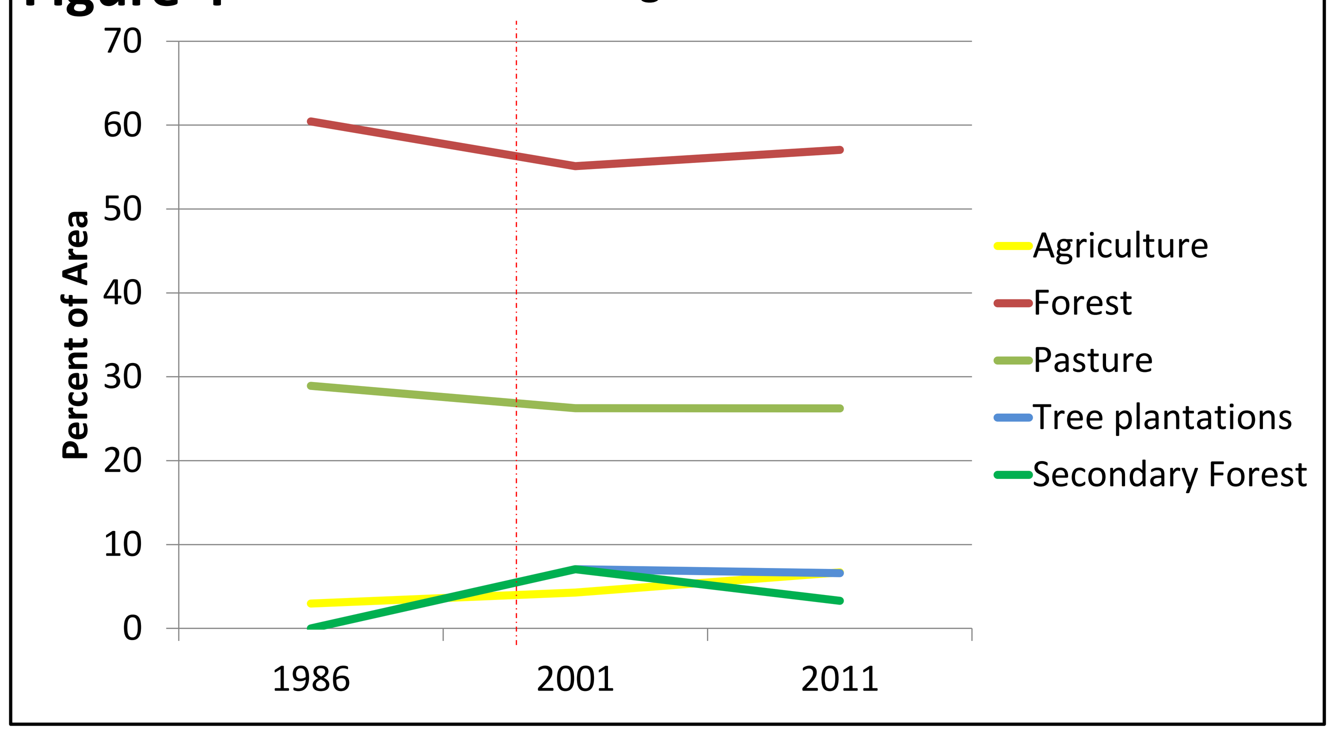
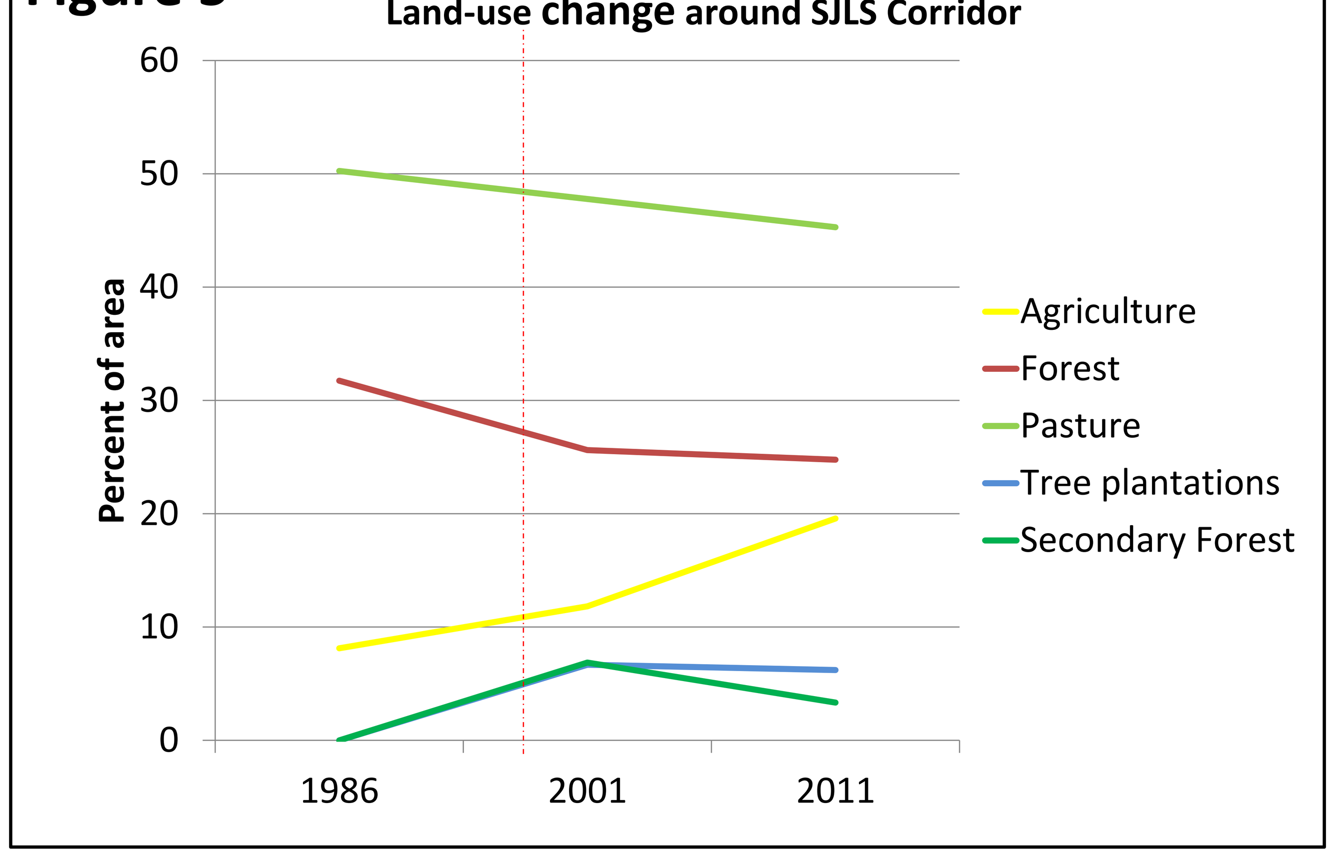


Figure 5



Figures 4 and 5: The percent of land area in each general land cover category within the San Juan-La Selva Biological Corridor (Fig. 4) and analysis buffers (Fig. 5). The dashed red line above indicates the date of enactment of the 1996 Forest Law.