Impact of Selective Logging on Phenology in Amazon Rain-Forests

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Introduction

Selective logging (**SL**) or partial forest removal in the Brazilian Amazon was recently shown in analyses of Landsat ETM+ data at 30-m spatial resolution to be occurring at rates of about 12,000–20,000 km² per year, thus indicating the central role of selective logging in tropical forest disturbance [1].

There has been few studies analyzing the effects of SL on forest phenology and no previous systematic study. In contrast to deforestation, rapid closure of relatively small canopy gaps following SL may appear similar to natural regeneration phenomena in forests. As a result, forest biospheric processes and functions, as represented by phenological trajectories seem unaffected. In turn, the absence of significant phenological changes would support the claim that selective logging is effective at maintaining background conditions of tropical forests.

To detect and characterize the regional or continental scale phenological changes associated with SL requires frequent observations over large geographic areas, necessitating the use of low spatial resolution satellite data. However, at the low spatial resolution, the spectral signal of small-scale forest clearings is subtle (Fig. 1), making identification of these impacts and separation from background forests extremely difficult.

A measure of logging intensity is given by Area-Integrated Gap Fraction (**AIGF**) [2], which provides a consistent estimate of canopy damage within logged forests. Higher AIGF values indicate a more open canopy and thus greater disturbance throughout the forest.

Study Questions and Outline

Given the prevalence of selective logging in Amazonian forests, and the uncertainty about forest function following timber harvest, **we sought to answer the basic question**:

1. Does or does not selective logging change phenological trajectories of the forest in the Brazilian Amazon?
And, if it does:
2. What are the characteristic features of these changes?
3. How long do the differences remain significant?
4. Are the changes pertinent to highly damaged forests only and insignificant if the initial canopy damage was low?

To date, none of these questions have been addressed.

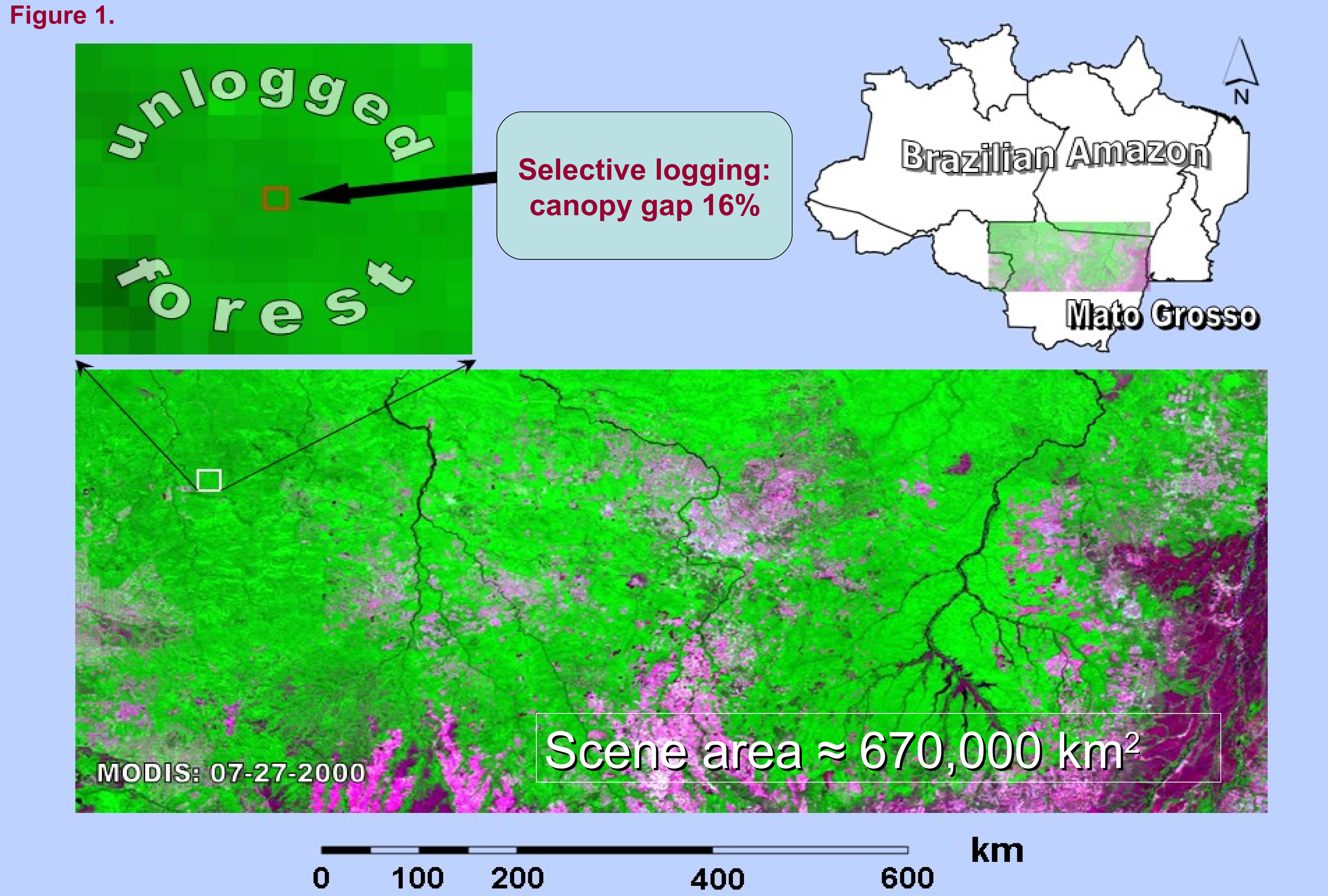
We studied phenological consequences of SL that occurred between 1999 and 2000 in Mato Grosso, Brazil (Fig. 1), using a time series of MODIS (MODerate Resolution Imaging Spectroradiometer) multi-spectral 1-km resolution imagery combined with AIGF estimates [1],[2] derived from Landsat 7.

Study Scene and MODIS Dataset

The scene used in this study is characterized by a large number of selective logging events that occurred between 1999 and 2000, with total logged area exceeding 13,000 km² [1].

We compiled 65 MODIS Nadir BRDF-Adjusted Reflectance images from Terra satellite spanning the interval from March 15, 2000 to December 31, 2002, at 16-day time steps.

Figure 1.



Methods

1. We extracted 74,432 forest pixels that had not been selectively logged or clear-cut after year 2000 until 2003, using:
   - PRODES deforestation maps for year 2002;
   - 1-km scale AIFG map of SL in 1999 – 2000;
   - 30-m scale maps of SL *events* occurred a) 2 between 2000–2001 and b) between 2001–2002.
2. These pixels were split into 9 disjoint groups, with respect to AIGF observed in 2000.
3. In each pixel, the time series of two MODIS vegetation indexes (VI) were computed:
   - Enhanced Vegetation Index (**EVI**)
   - Normalized Difference Water Index (**NDWI**).

- For each VI, we computed the **impact** time series: $\Delta V(s, t) = V(s, t) - W(s, t)$, where $W(s, t)$ = mean VI value of unlogged neighboring forests (inside a 20-km window), and $V(s, t)$ is the observed value of VI.

Table 1. Phenological Impact Parameters

Represents	Greenness (EVI)	Canopy Moisture (NDWI)
Dry Season (May 8 –Aug 13)	Overall Seasonal Greenness Impact	Overall Seasonal Moisture Impact
Dry Season (May 8 –Aug 13)	Seasonal Greenness Impact Trend	Seasonal Moisture Impact Trend
Green-up Season	Shift in greenness onset time	----
Green-up Season	Shift in greenness offset time	----
Green-up Season	Shift in green-up season timing (midpoint)	----
Green-up Season	Shift in green-up season length	----
Green-up Season	Change in greenness at the greenness onset time	----
Green-up Season	Change in greenness at the greenness offset time	----

Methods

- Using orthogonal polynomial modeling of $\Delta V(s, t)$, $V(s, t)$, and $W(s, t)$, we computed phenological impact parameters (Table 1) related to:
  - Dry Season (May 8 – August 13 in 2000, 2001, and 2002)
  - Green-up Season (between greenness minimum and maximum)
- Additional sites logged in 2001 (6,294 pixels) and 2002 (5,372 pixels), were used to estimate and remove biases in the impact parameters due to conditions of the forest prior to logging.
- For each impact parameter, we applied permutation significance tests of the differences in means, and in 10%-trimmed means between each SL group (grouped by AIGF) and the unlogged forest (AIGF =0) versus one-sided alternative hypotheses. The same number of permutations, 10,000, were used in all tests.

Results: Greenness and Canopy Moisture Impact in the *Dry Season*

Figure 2. Trajectories of Impacts

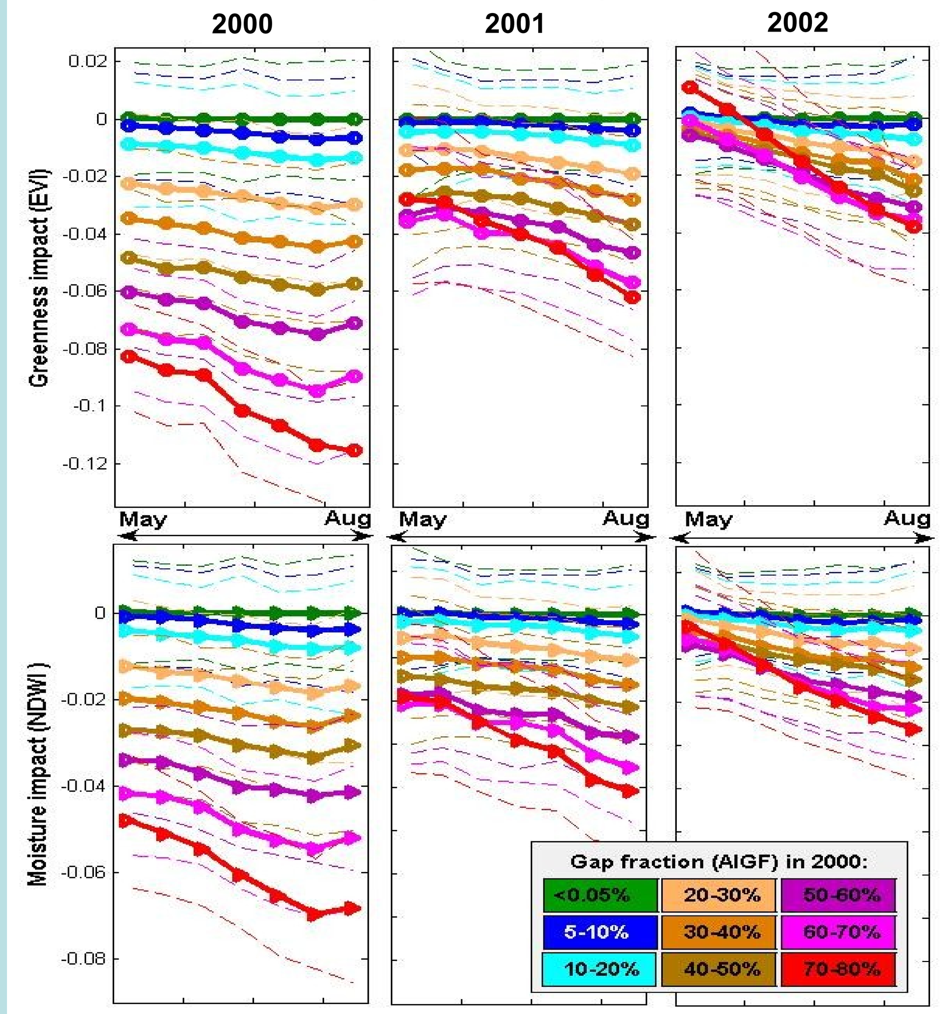
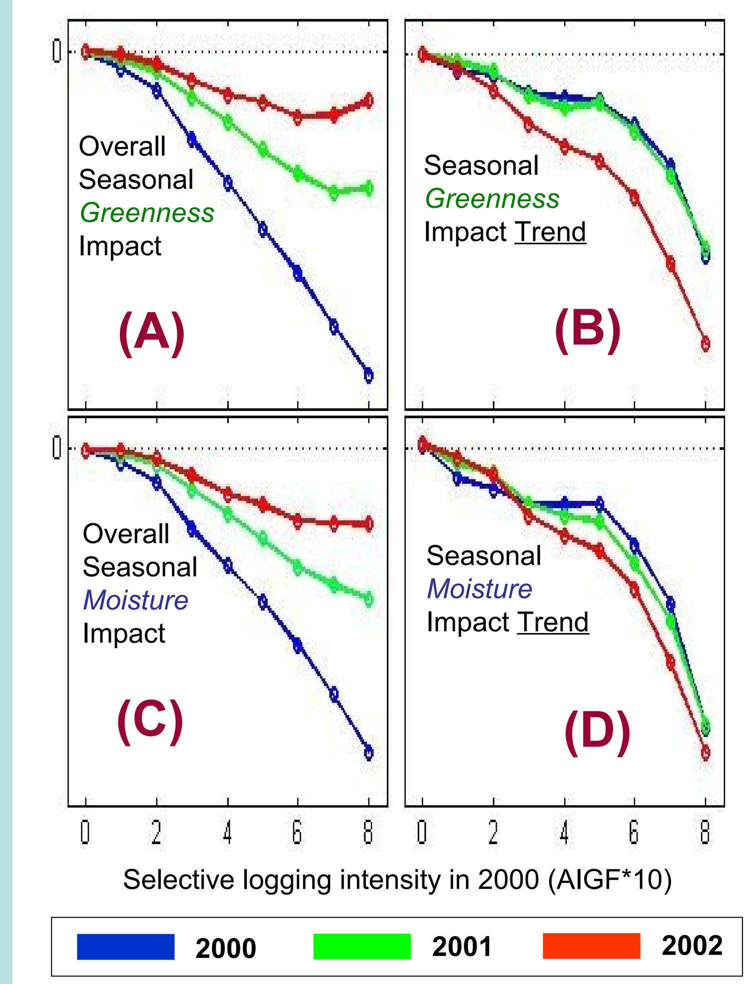
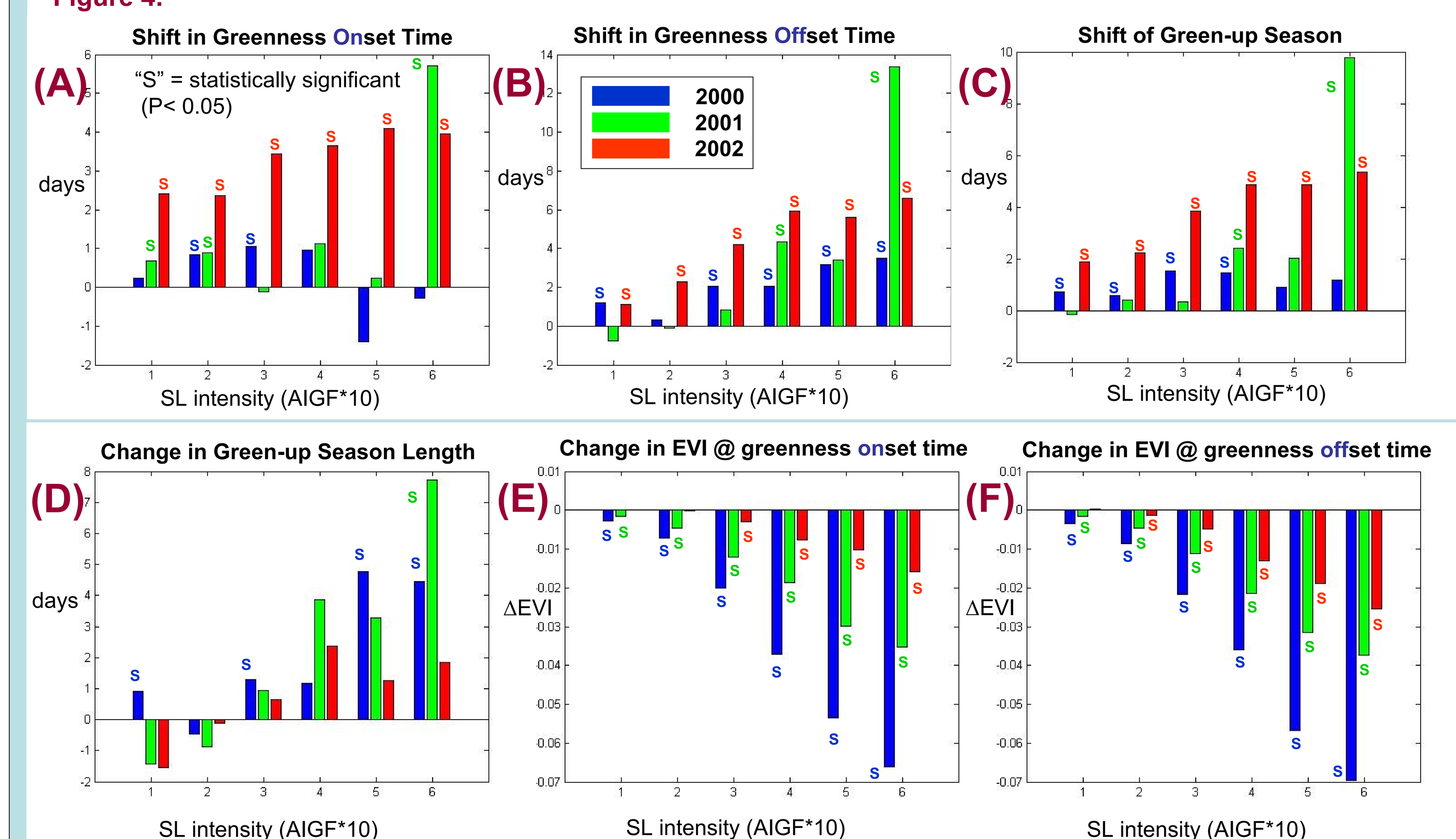


Figure 3. Inter-Annual Dynamics of Dry-Season Impacts



Results: Changes in *Green-up Season* Timing and Greenness (EVI)

Figure 4.



Statistical analysis confirms:

- The **dry-season** impact parameters of selectively logged forests **are significantly negative and less than those of unlogged forests**, mostly exhibiting a monotonic increase in magnitude as AIGF grows (Fig. 2).
- The dry-season greenness impact parameters, are **significant** (P<0.0001) **even to the 5–10% disturbance level, and through the third year after selective logging;**
- With years following logging events, the magnitude of the overall seasonal impacts decreases at the observed rate of 52% (±11%) a year (Fig. 3 A,C), consistent with field observations of gap closure rates [3]. After three years, the overall VIs are nearly recovered to the values of neighboring unlogged forest
- Not only do the **greenness impact <u>trend</u> and moisture impact <u>trend</u> not recover in the three year time interval, there is no evidence that the impact trends are converging to those of the intact forest** (Fig. 3 B,D);
- The impacts were found statistically significant using both metrics: mean and 10%-trimmed mean.
- Selectively logged forests **begin and end to green-up later than neighboring unlogged forests**, with lower EVI at the greenness onset and offset times (Fig. 4).

Conclusions:

Selective logging leading to just 5–10% canopy damage has a significant and long-lasting (> 3 years) effect on forest phenology in the Brazilian Amazon.

1. **During the Dry season, selective logging::**
   - **slows down forest green-up in the dry season,**
   - **progressively dehydrates canopy, and**
   - **induces overall seasonal deficits in canopy moisture and greenness.**
2. **Selective logging changes timing of the green-up season, however, there are additional factors influencing these differences.**

- **Phenological impact of SL is not explained by the gap closure processes following logging, and also may not be attributed to low-probability compounding disturbance events, e.g. fires following selective logging.**
- **Spreading logging operations over large areas does not completely mitigate functional changes to forests following timber extraction.**
- **Our findings highlight the need to further evaluate, model, and incorporate the altered post-logging phenology of tropical forests into carbon and climate models. In this way, one will be able to quantify the relationship between phenological impact and carbon budget at various spatial and temporal scales.**

References

[1] Asner, G. P., Knapp, D. E., Broadbent, E. N., Oliveira, P. J. C., Keller, M., and Silva, J. N. (2005). Selective logging in the Brazilian Amazon. *Science*, 310, 480–482.
[2] Asner, G. P., Broadbent, E. N., Oliveira, P. J. C., Keller, M., Knapp, D. E., and Silva, J. N. (2006). Condition and fate of logged forests in the Brazilian Amazon. *Proc. Natl. Acad. Sci.* USA, 103(34), 12947–12950
[3] Asner, G. P., Keller, M., Pereira, R., Zweede, J. C., and Silva, J. N. (2004). Canopy damage and recovery after selective logging in Amazonia: field and satellite studies. *Ecological Applications*, 14(4), S280–S298.

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