An Assessment of Deforestation Models for Reducing Emissions from Deforestation & forest Degradation (REDD)
A Case Study of Chiquitanía, Bolivia

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Background

What’s REDD?

- Carbon credit is a new monetary system [UN FCCC 1998].
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- A carbon offset project must prove additional carbon benefit to generate carbon credits [IPCC 2000].
  - Afforestation
  - Reforestation
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  - REDD: Reducing Emissions from Deforestation & Degradation
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  - REDD: Reducing Emissions from Deforestation & Degradation

UN-REDD
- The United Nations Collaborative Programme on Reducing Emissions from Deforestation and Forest Degradation in Developing Countries [UN-REDD 2008].
- Website: http://www.un-redd.org
Why LUCC modeling?

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- Land-use and land-cover change (LUCC) modeling can systematically simulate business-as-usual deforestation.
Why LUCC modeling?

- In the case of REDD, the additional carbon benefit is calculated based on business-as-usual deforestation (i.e., baseline).
- Land-use and land-cover change (LUCC) modeling can systematically simulate business-as-usual deforestation.
- Its result can be later combined with the corresponding carbon content’s map.
General scope of the research

1. This paper proposes a modular framework to assess accuracy of a spatially-explicit REDD baseline by demonstrating the comparison of two LUCC modeling approaches.
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1. This paper proposes a modular framework to assess accuracy of a spatially-explicit REDD baseline by demonstrating the comparison of two LUCC modeling approaches.

2. It compares the performance of “GEOMOD Modeling (GM)” and “Land Change Modeler (LCM)” for simulating baseline deforestation of multiple transitions based on model structure and predictive accuracy.
Research questions

1. How do GM’s linear extrapolation and LCM’s Markov Chain compare in terms of quantity of LUCC (for multiple transition modeling)?
Introduction

Objectives

Research questions

1. How do GM’s linear extrapolation and LCM’s Markov Chain compare in terms of quantity of LUCC (for multiple transition modeling)?

2. How do GM’s empirical frequency, LCM’s logistic regression, and LCM’s multilayer perceptron compare in terms of (spatial) allocation of LUCC, measured by relative operating characteristics, figure of merit, and multiple resolution analysis?
Environmental variables

- Distance from disturbance (meter)
- Distance from roads (meter)
- Distance from streams (meter)
- Distance from cities (meter)
- Elevation (meter)
- Slope (degree)
Multiple transition modeling

- Transition refers to a process in which something undergoes a change from one land-type (e.g., forest) to another (e.g., anthropogenic).
- There is a need of modeling multiple transitions in REDD projects since there can be numerous transitions due to different types of land management.
Calibration and validation

- The common essence of these validation processes is separating data for calibration and validation.
Quantity of LUCC

- Linear extrapolation (GM)
- Markov Chain (LCM)
Introduction

Methodology

Results

Conclusion

Other information

Model structure

Allocation of LUCC (or transition potential map)

- Empirical frequency (EmpFreq)
  - Is clear to interpret the output;
  - Has information of variables’ contributions;
  - Subjective input: number of bins/width of bins.
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- **Logistic Regression (LogReg)**
  - Is easier to interpret the output than MLP (i.e., linear estimation);
  - Has information of variables’ contributions;
  - Subjective input: statistical significance test.
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- **Multilayer perceptron (MLP)**
  - Is complex and often limits interpretation (i.e., nonlinear & black box-like estimation);
  - Has no information of variables’ contributions;
  - Subjective input: network training parameters.
Map comparison measurements

- Relative operating characteristic (ROC)
  - Assesses the predictive accuracy of a transition potential map by comparing the transition potential map with a reference map that shows the occurrence of binary events;
  - Can be roughly summarized by an Area Under the ROC Curve (AUC).

- Figure of merit
  - Assesses the predictive accuracy of a simulated LUCC by simply overlaying the land-cover map of 1994, the land-cover map of 2000 and the predicted map of 2000;
  - Has both visual and numeric expressions (Figure of merit statistics).
Map comparison measurements (con’d.)

- **Multiple resolution analysis**
  - Assesses how closely in space the simulated LUCC is to the reference LUCC;
  - Compares each simulation map to its reference map by aggregating pixels to coarser resolutions;
  - Assumes “persistence” as the prediction of future LUCC that experiences no change;
  - Employs a “null resolution,” and more precise LUCC simulations have finer null resolutions.
Linear extrapolation vs. Markov Chain

**Linear extrapolation** makes sense when there is only one transition of land-cover change, e.g., undisturbed forest to disturbed forest.

**Markov Chain** is applicable for multiple transition modeling.
Transition potential: Forest to anthropogenic

a Empirical frequency
b Logistic regression
c Multilayer perceptron
Transition potential: Savanna to anthropogenic

- Empirical frequency
- Logistic regression
- Multilayer perceptron
ROC: Forest to anthropogenic
ROC: Forest to anthropogenic (Zoom-in)
ROC: Savanna to anthropogenic
ROC: Savanna to anthropogenic (Zoom-in)
**Figure of merit**

- Error due to observed change predicted as persistence
- Correct due to observed change predicted as change
- Error due to observed persistence predicted as change
- Correct due to observed persistence predicted as persistence

a  Empirical frequency  b  Logistic regression  c  Multilayer perceptron
Multiple resolution analysis: EmpFreq

![Graph showing multiple resolution analysis for EmpFreq](image)

- EmpFreq % correct
- EmpFreq % correct at the coarsest resolution
- Persistence % correct
- Persistence % correct at the coarsest resolution
Multiple resolution analysis: LogReg
Multiple resolution analysis: MLP

![Graph showing multiple resolution analysis](image)

- MLP % correct
- MLP % correct at the coarsest resolution
- Persistence % correct
- Persistence % correct at the coarsest resolution
### AUCs: Forest to anthropogenic

<table>
<thead>
<tr>
<th>Model</th>
<th>AUC</th>
<th>$AUC_p$</th>
<th>$AUC_t$</th>
</tr>
</thead>
<tbody>
<tr>
<td>EmpFreq</td>
<td>0.800</td>
<td>0.000274</td>
<td>0.00444</td>
</tr>
<tr>
<td>LogReg</td>
<td>0.791</td>
<td>0.000304</td>
<td>0.00477</td>
</tr>
<tr>
<td>MLP</td>
<td>0.813</td>
<td>0.000300</td>
<td>0.00479</td>
</tr>
</tbody>
</table>
## AUCs: Savanna to anthropogenic

<table>
<thead>
<tr>
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<th>$AUC_p$</th>
<th>$AUC_t$</th>
</tr>
</thead>
<tbody>
<tr>
<td>EmpFreq</td>
<td>.706</td>
<td>.001415</td>
<td>.01088</td>
</tr>
<tr>
<td>LogReg</td>
<td>.741</td>
<td>.001422</td>
<td>.01266</td>
</tr>
<tr>
<td>MLP</td>
<td>.703</td>
<td>.001034</td>
<td>.00772</td>
</tr>
</tbody>
</table>
# Figure of merit & null resolution

<table>
<thead>
<tr>
<th>Model</th>
<th>Figure of merit</th>
<th>Null resolution</th>
</tr>
</thead>
<tbody>
<tr>
<td>EmpFreq</td>
<td>6.62%</td>
<td>2.4~4.8km</td>
</tr>
<tr>
<td>LogReg</td>
<td>8.0%</td>
<td>1.2~2.4km</td>
</tr>
<tr>
<td>MLP</td>
<td>6.57%</td>
<td>about 2.4km</td>
</tr>
</tbody>
</table>
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LCM is better than GM!

Based on the model structure and predictive accuracy comparisons, the LCM seems more suitable than the GM to construct a REDD baseline when considering multiple transitions.

1. The embedded Markov Chain can estimate the quantity of LUCC for multiple transitions, while it is challenging for linear extrapolation to do so;

2. The LCM’s LogReg has the highest predictive accuracy in most cases (it is important to note that MLP contains a stochastic element).
Predictive accuracy

- From a land change scientist’s point of view, the differences, measured by ROC, figure of merit, or multiple resolution analysis, must be statistically tested to check out how significantly they differ.

- It is invalid to employ a traditional $t$ test or Mann-Whitney $U$ test to measure such differences since those are not independent samples of observations.
Carbon implication

▶ Most likely, a carbon mass map of rainforests will contain a confidence interval to indicate its measurement precision.

▶ If the difference (in terms of carbon mass) between two LUCC modeling approaches falls into the confidence interval of the carbon mass measured then it seems reasonable to regard the difference (in terms of predictive accuracy) between the two LUCC modeling approaches as insignificant.
Empirical frequency (EmpFreq)

\[ R(i) = \frac{\sum_{a=1}^{A} W_a P_a(i)}{\sum_{a=1}^{A} W_a} \]  

where \( R(i) \) is a transition potential value in pixel \((i)\), \( a \) indicates a particular environmental variable, \( A \) indicates the total number of environmental variables, \( W_a \) is the weight of environmental variable \( a \), and \( P_a(i) \) indicates the percent of LUCC during the calibration interval in the bin to which pixel \( i \) belongs for variable \( a \).
Logistic regression (LogReg)

\[
P(y = 1|X) = \frac{\exp \sum BX}{1 + \exp \sum BX} \quad (2)
\]

where \( y \) is a binary event, \( P \) is the probability of the binary event given column vector \( X \), \( X \) is a column vector that give the values of the environmental variables, and \( B \) is a row vector that gives the estimated coefficients.
Area Under the ROC Curve

\[ AUC = \sum_{i=1}^{n} (x_{i+1} - x_i) \times \left\{ y_i + \frac{(y_{i+1} - y_i)}{2} \right\} \]  

(3)

where \( x_i \) is the false positives for the threshold \( i \), \( y_i \) is the true positives for threshold \( i \), and \( n + 1 \) is the number of thresholds.
**Figure of Merit**

\[
\text{Figure of Merit statistics} = \frac{B}{(A + B + C)} \quad (4)
\]

where \(A\) is a number of pixels for “error due to observed change predicted as persistence” (or misses), \(B\) is a number of pixels for “correct due to observed change predicted as change” (or hits), \(C\) is a number of pixels for “error due to observed persistence predicted as change” (or false alarms). The Figure of Merit statistics range from 0 to 100 percent, where 100 percent indicates perfect prediction.
Intergovernmental Panel on Climate Change (IPCC) 2000
*Summary for Policymakers–Land Use, Land-Use Change and Forestry.*


Author’s information

- Research interest
  - REDD

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  - M.A. in GISc for Development & Environment
  - Ph.D. Student in Geography

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- Questions?