The Abdus Salam International Centre for Theoretical Physics

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# Forest-Sage: A new deforestation and land use scenario generator designed to integrate with climate models

Luca Caporaso
*ICTP - Trieste*

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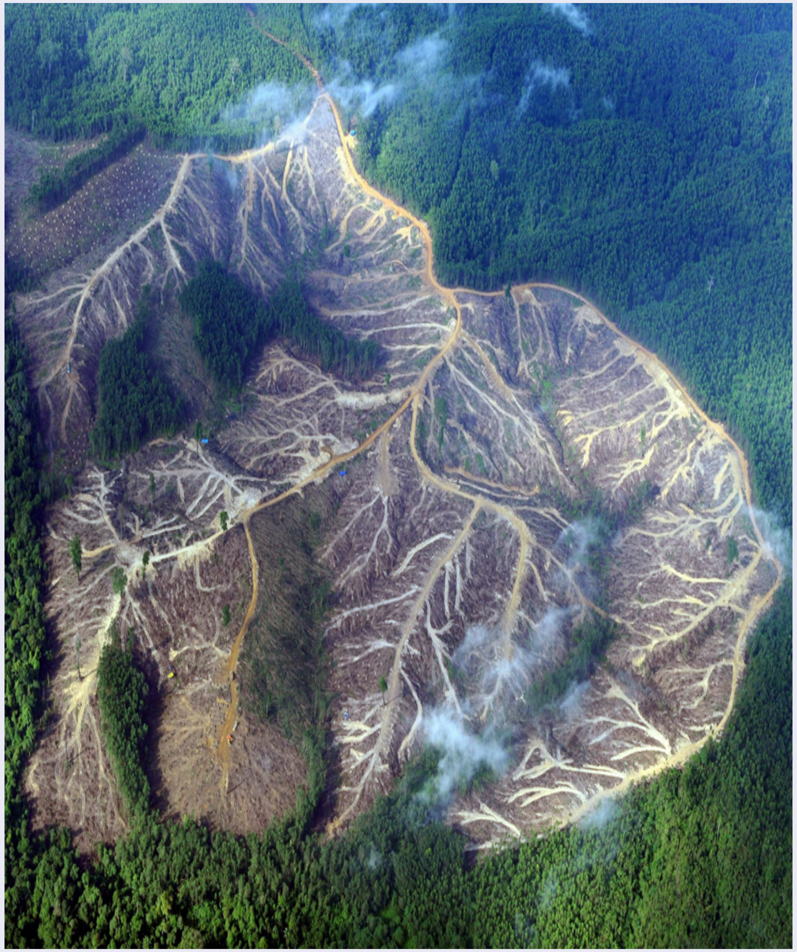
Luca Caporaso, Adrian M. Tompkins, Riccardo Biondi and Jean-Pierre Bell

Earth System Physics, ICTP, Trieste, Italy

# Introduction

## Deforestation

- The Deforestation and forest degradation accounts for between $10-15\%$ of global human-induced greenhouse gas (GHG) emissions (Van der Werf et al. 2009 Nature Geoscience 2:737â738)
- In the last 300 years $> 25\%$ of forests have been permanently cleared (Hurtt 2006 Global Change Biology 12:1208-1229)
- Effects on regional-global weather, hydrology and climate (eg Pitman 2009 GRL 36:L14814)

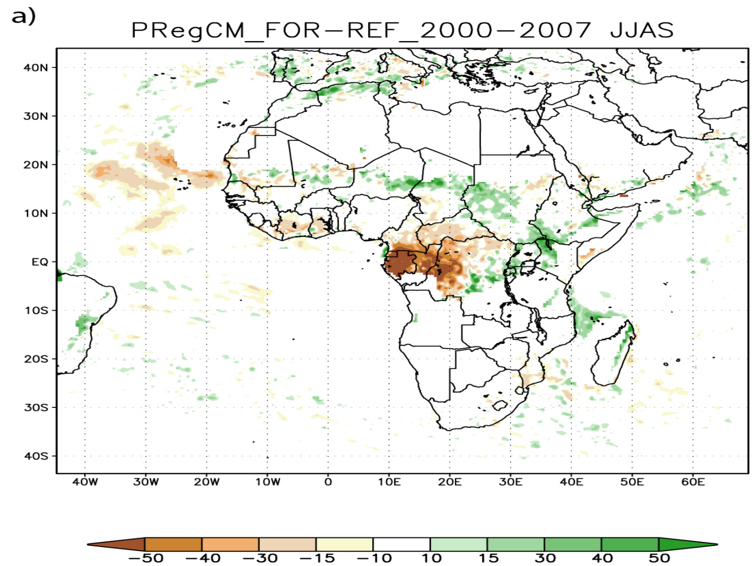


http://www.foodbeautylove.com/our-environment/

# Deforestation Impacts

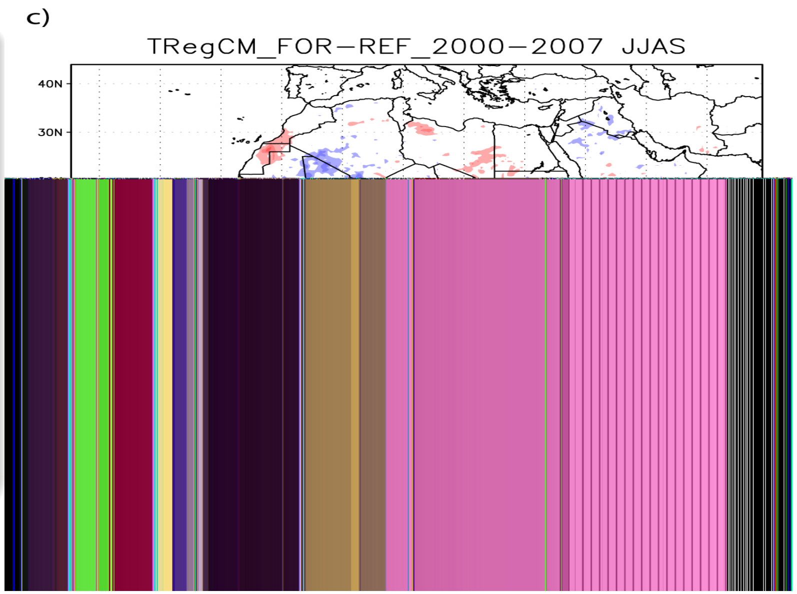
On top of the loss of habit and species diversity, deforestation also has an impact on climate :

- Indirect global effect via $CO_2$ emission
- Direct local effect: land use change, albedo, drag, latent and sensible heat flux




**A model outputs example** *Nogherotto et al. 2012*

- BATS RegCM coupling (7yrs)
- Decrease of precipitation locally up to 50%
- Temperature increase up to 2-4 $^oC$



# Deforestation Estimates from macroregion

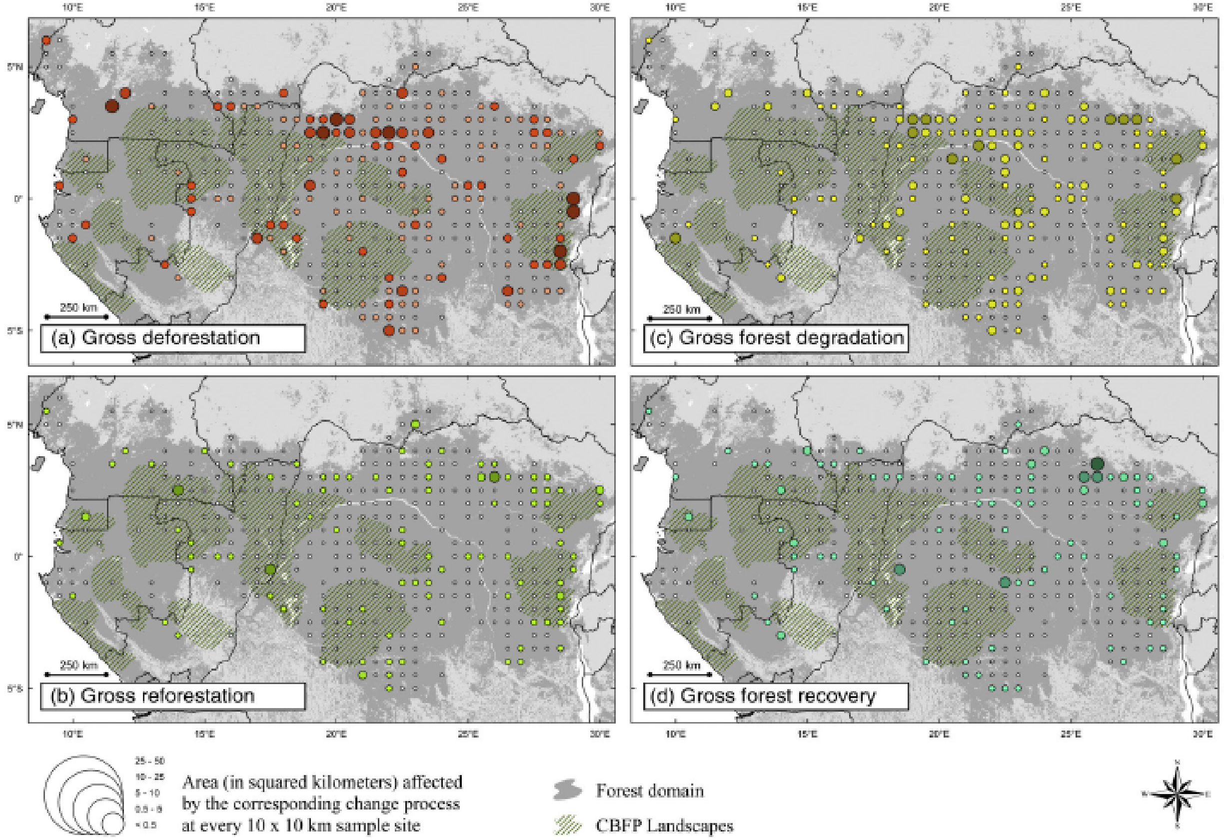
**FAO report 2011:** *The State of Forest in the Amazon Basin, Congo Basin and Southeast Asia - Annual deforestation rates*

*Reference Period 2000-2010*

- Amazon basin -0.44%
- Congo Basin -0.23%
- SouthEast Asia -0.41%

Remote sensing and ground observations used to assess present deforestation, degradation and reforestation rates.

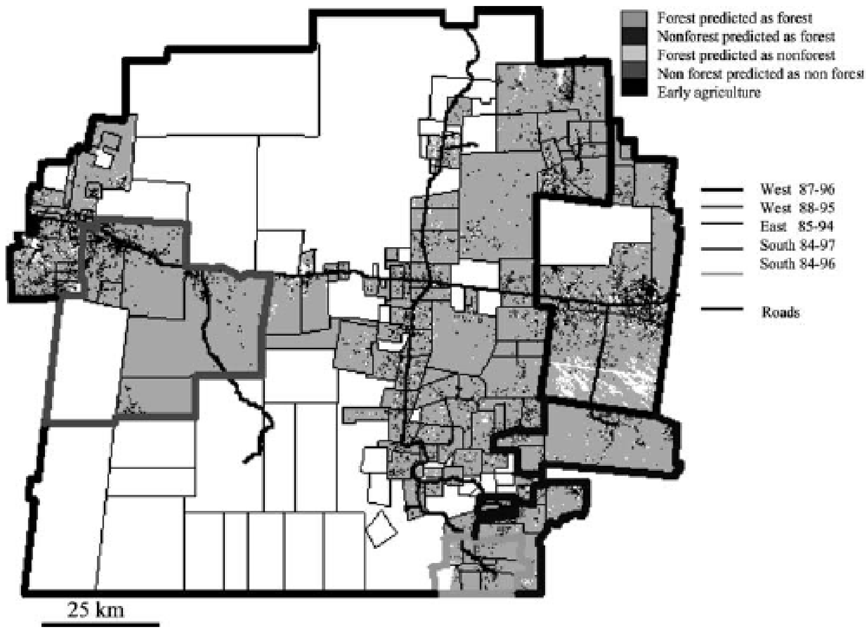
Example: Duveiller et al. 2008: Remote Sensing of Environment 112, 1969-1981



## Deforestation models: statistical models

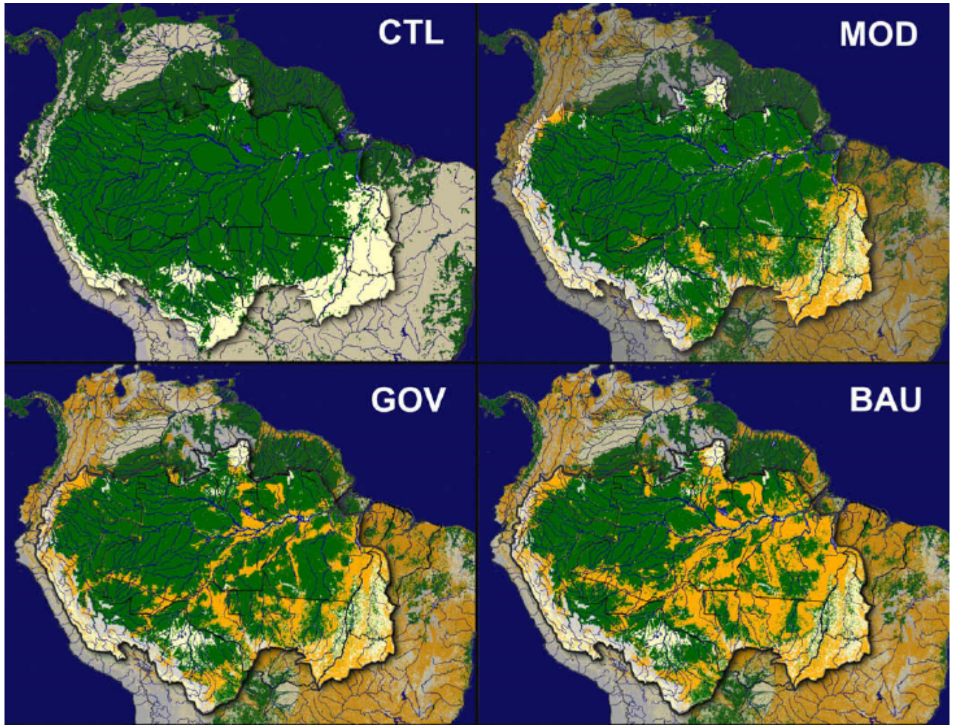
- detailed picture of deforestation often for small-scale regions
- local deforestation drivers (roads, parks, urban centres) are input to a statistical model to reproduce past deforestation patterns
- can be used to determine short-to-medium term deforestation risk zones, assuming unchanging deforestation drivers
- but do not account for future changes in macro socioeconomic drivers of deforestation

Example of Geohegan et al. 2004, GeoJournal 61: 353-363, modeling deforestation in the southern Yucatán region



## Deforestation models: dynamic scenario models

- wider region scenarios for longer term future deforestation
- Account for local drivers such as roads and parks
- Embedded in generic scenarios, e.g.:
  - Business as Usual BAU - no new parks, poor policy implementation
  - Good Governance GG - new parks, strict policy

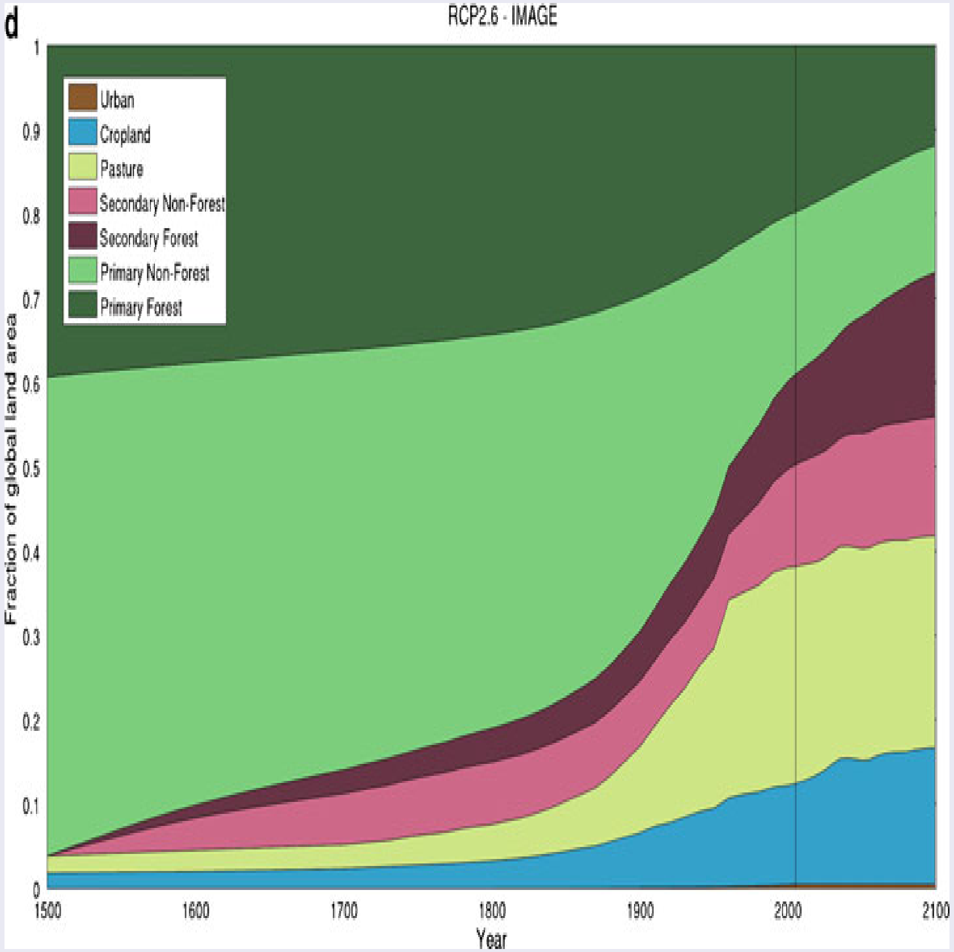



- Example from Coe et al. (2009) using Soares-Filho et al. (2006) model
- Such stand-alone models often not linked to global land surface schemes

# IAMs and HYDE 3.1

- Harmonization of land-use hystorical data with future scenarios
- IAMs just consider few categories of LU:(eg pasture, cropland, primary forest ) with some internal inconsistencies
- Need to interpret few categories in terms of 15+ categories of Land Models (eg CLM 17 categories)
- Need to pass on a fully coupled model for land use change

## RCPs scenario

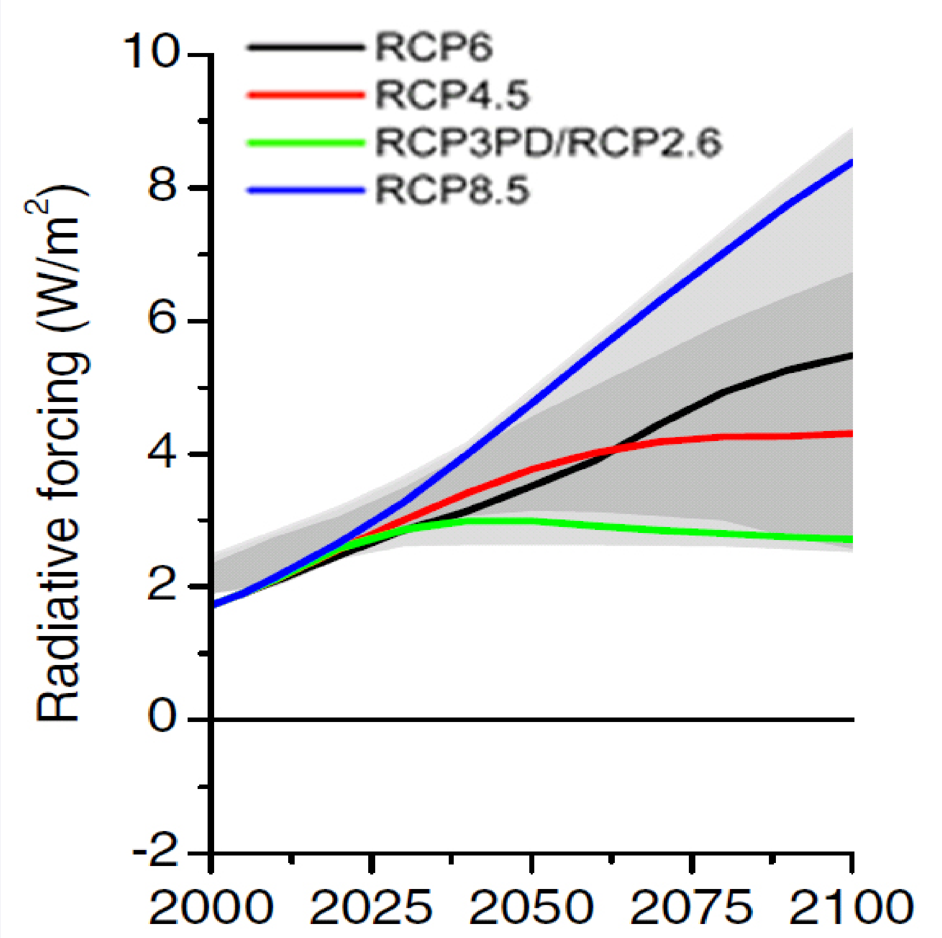



Hurtt et al. 2011: Climate Change 109:117-161

# Hyde 3.1 and future scenarios

- Four RCP scenarios (provided by IAM) of the future 2005 – 2100 used as input to the ESMs for future carbon-climate projections (Moss 2010 Nature 463:747-756)
- RCP datasets and Hyde 3.1 are used to drive CMIP5 climate model simulations in the AR5 report
- ESMs can evaluate the biogechemical and biogeophysical effects of land-use changes on the Earth's climate system

**RCPs scenario**




CMIP5 - Coupled Model Intercomparison Project Phase 5

# FOREST-SAGE: deFORESTation and land-use change ScenArio GEnerator

## Climate studies:

- Many climate studies use highly idealized all-or-nothing deforestation scenarios.
- Prevents analysis of nonlinear climate responses and tipping points
- Heterogeneity in the deforestation pattern also neglected, e.g. logging concessions and national parks

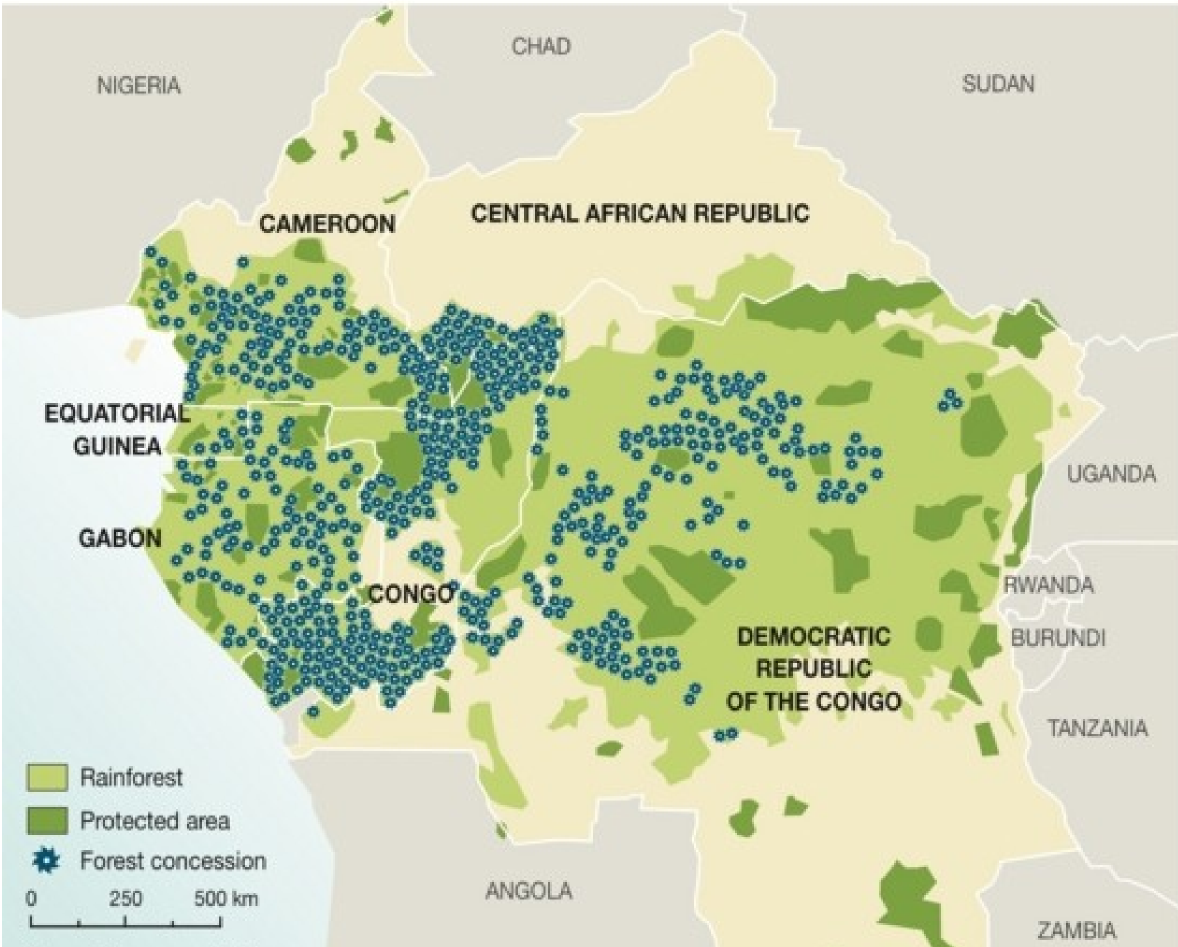
## Deforestation models:

- Often only for local or regional scale
- Many account for past drivers only and can not provide long-term projections
- Not designed to link easily to climate models

Need for a generic flexible deforestation model accounting for both macro-scale socio-economic and local-scale drivers of deforestation, interfaced to dynamic vegetation land surface schemes for coupling to climate models

# FOREST-SAGE - STEP 1
## define forest macroregions

- Macro-regions will allow different deforestation drivers to be applied according to the relevant macro and local-scale pressures.
- In this preliminary study, we only have one region for central Africa:



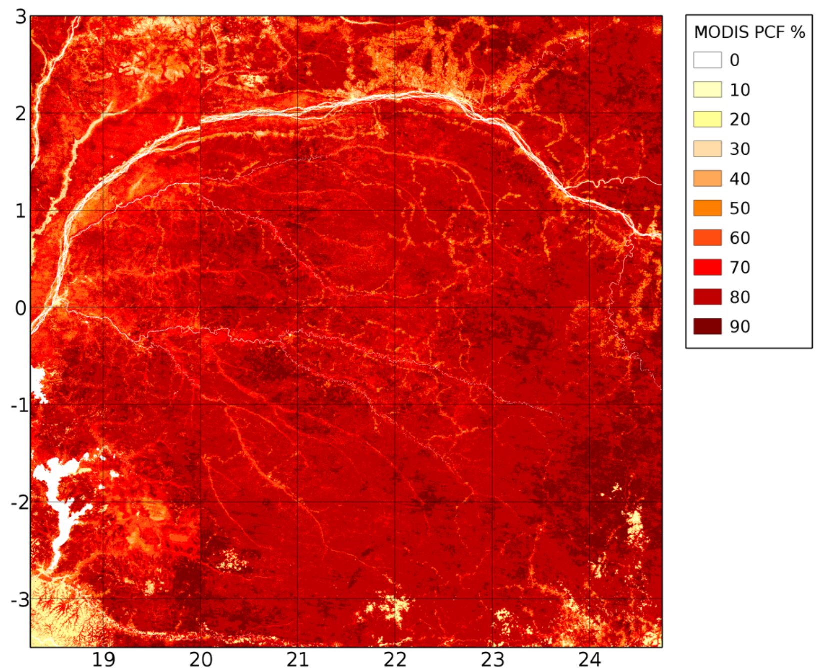
# FOREST-SAGE - STEP 2
## define deforestation pathway for each MR

Forest Sage can be initialized with different inputs and at diffent resolutions: satellite images (eg MODIS-VCF) or land use matrices (eg CLM v3.5)

### MODIS VCF

- MODIS VCF ( 2000 to 2010) with 250 meters spatial resolution :
- PCF is the amount of tree canopy covering each pixel (ranging from 0 to 100)
- QA cloudy data / QA bad data

### MODIS VCF 2001

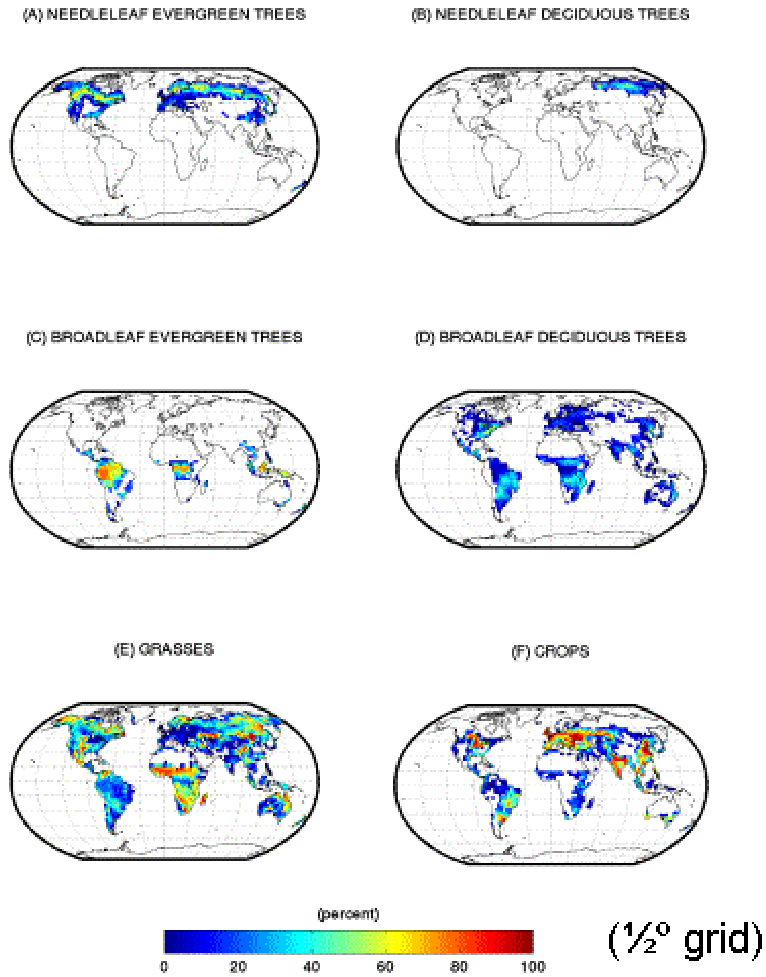


# FOREST-SAGE - STEP 2
## define deforestation pathway for each MR

### Community Land Model

- CLM is a widely used land model
- global land points into 5.5 km grid of plant-function type (PFT) tiles describing 17 land cover types
- The PFT determines the plant physiology:leaf optical properties, root profile and thereby affects the surface fluxes, the hydrological cycle and the soil water content.

Geography of present-day PFT groupings in CLM



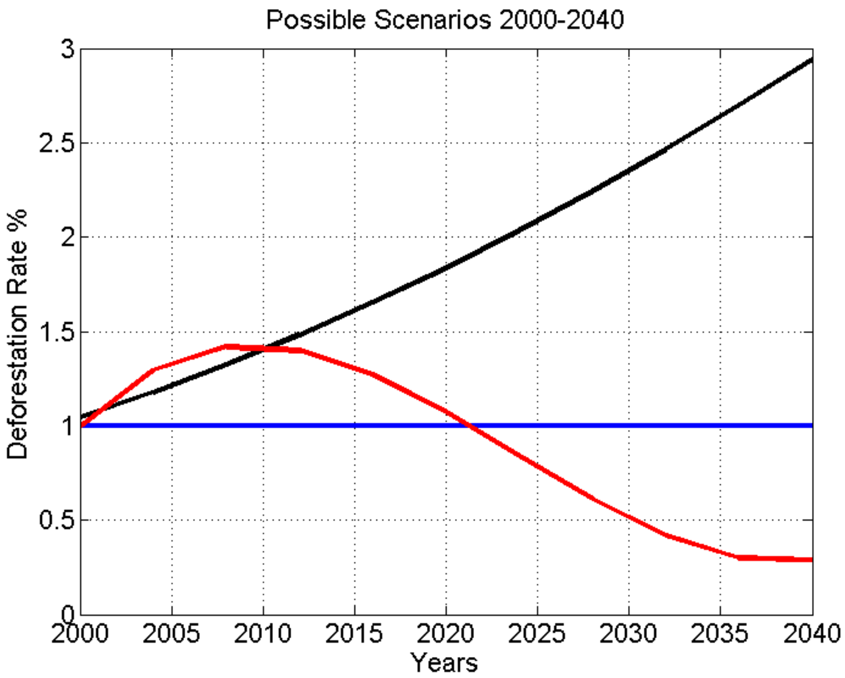
# FOREST-SAGE - STEP 2
## define deforestation pathway for each MR

- For each macro region FOREST-SAGE defines PFT pathways
- These can be simple 1-1 relationships (see fig)
- ...or from/to multiple classes

| PFT | CLM CATEGORIES |
|---|---|
| 0 | not vegetated |
| 1 | needleleaf evergreen temperate tree |
| 2 | needleleaf evergreen boreal tree |
| 3 | needleleaf deciduous boreal tree |
| 4 | broadleaf evergreen tropical tree |
| 5 | broadleaf evergreen temperate tree |
| 6 | broadleaf deciduous tropical tree |
| 7 | broadleaf deciduous temperate tree |
| 8 | broadleaf deciduous boreal tree |
| 9 | broadleaf evergreen shrub |
| 10 | broadleaf deciduous temperate shrub |
| 11 | broadleaf deciduous boreal shrub |
| 12 | c3 arctic grass |
| 13 | c3 non-arctic grass |
| 14 | c4 grass |
| 15 | corn |
| 16 | wheat |

# FOREST-SAGE STEP 3
## define the macro-scale scenarios

Analogous to IPCC scenarios (RCPs), a macro-scale scenario is defined to determine future deforestation rates (eg. IAMs driven)



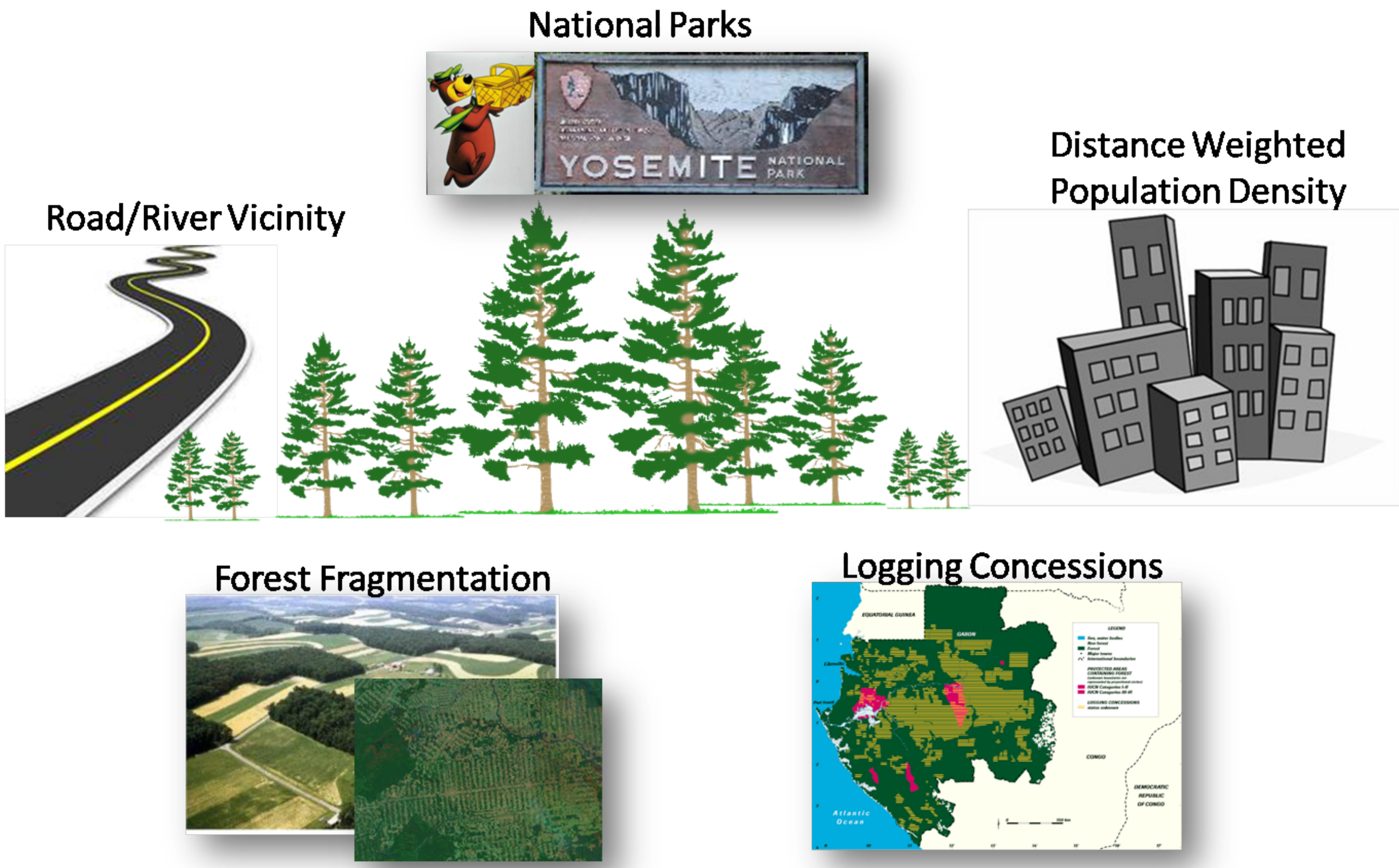

e.g. potential scenarios:

- Business as usual
- Increasing deforestation rate
- Increasing deforestation, coming to senses

These could become a function of the deforestation rate or climate.

# FOREST-SAGE STEP 4
## disagregate deforestation spatially

The deforestation rate is proportional to risk in each cell, but scaled to give the macro deforestation rate $D_k(t)$ for each macroregion.

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## Local factors $r$:

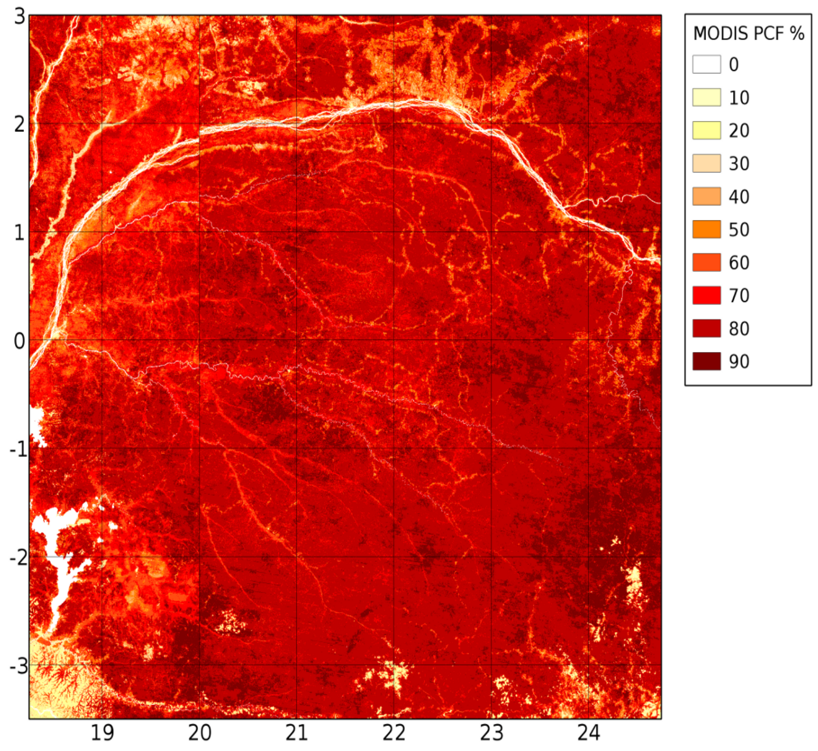
- The total deforestation risk is $r = r_{road} r_{river} r_{pop} r_{park} r_{log} r_{tree}$:
- $r_{road}$ the proximity to the roads (Digital Atlas of the World)
- $r_{river}$ the vicinity to the rivers (Digital Atlas of the World)
- $r_{pop}$ distance weighted population density (www.AfriPop.org)
- $r_{park}$ the presence of protected parks (www.wdpa.org)
- $r_{log}$ the logging concession
- $r_{tree}$ tree fragmentation (from PFT files)

These are set using literature as far as possible - but a local user with local knowledge can refine these for a local macroregion.

# Model Experiment

## Model set up

- Domain:Congo Basin [-4 4 18 25]
- Initialize the experiment by MODIS VCF 2001 (9 years run) 5 Km
- Validate output MODIS VCF 2010 50 km
- Used a linear trend to average out the noise
- Ensemble is needed

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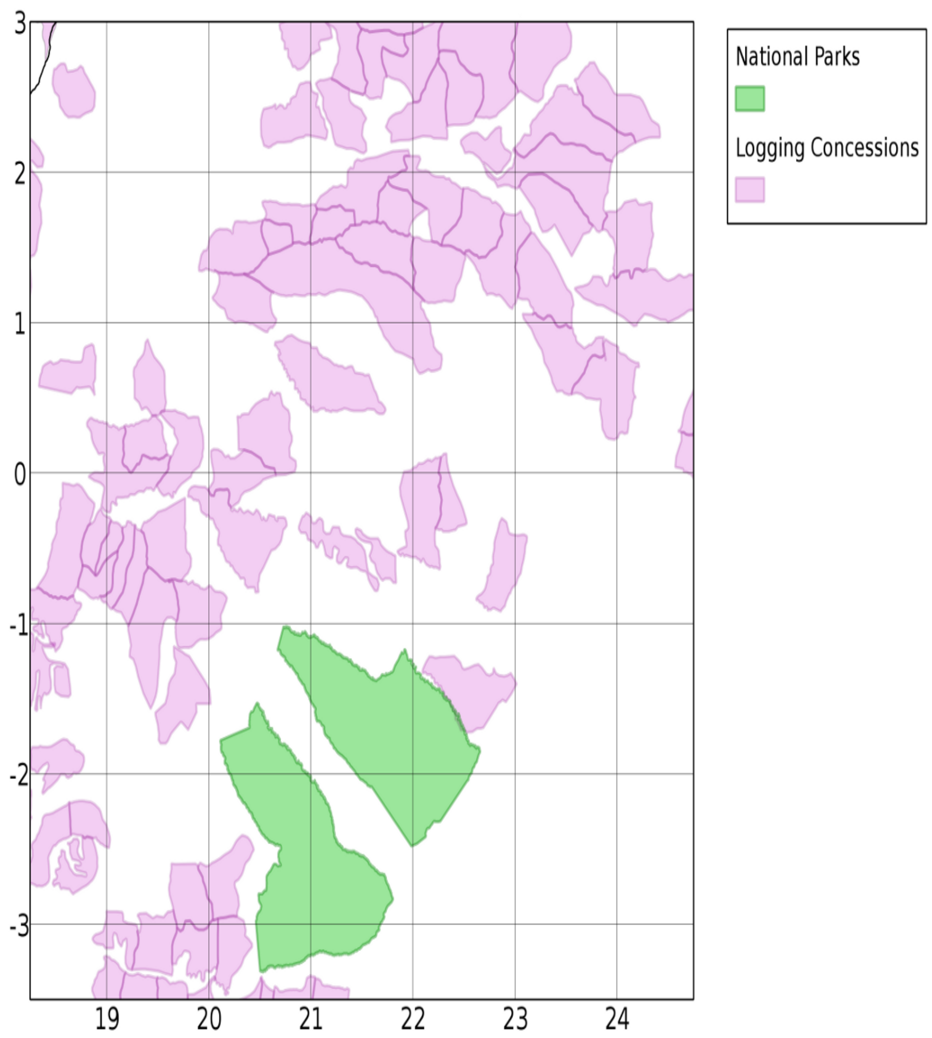
# Parks and logging concessions

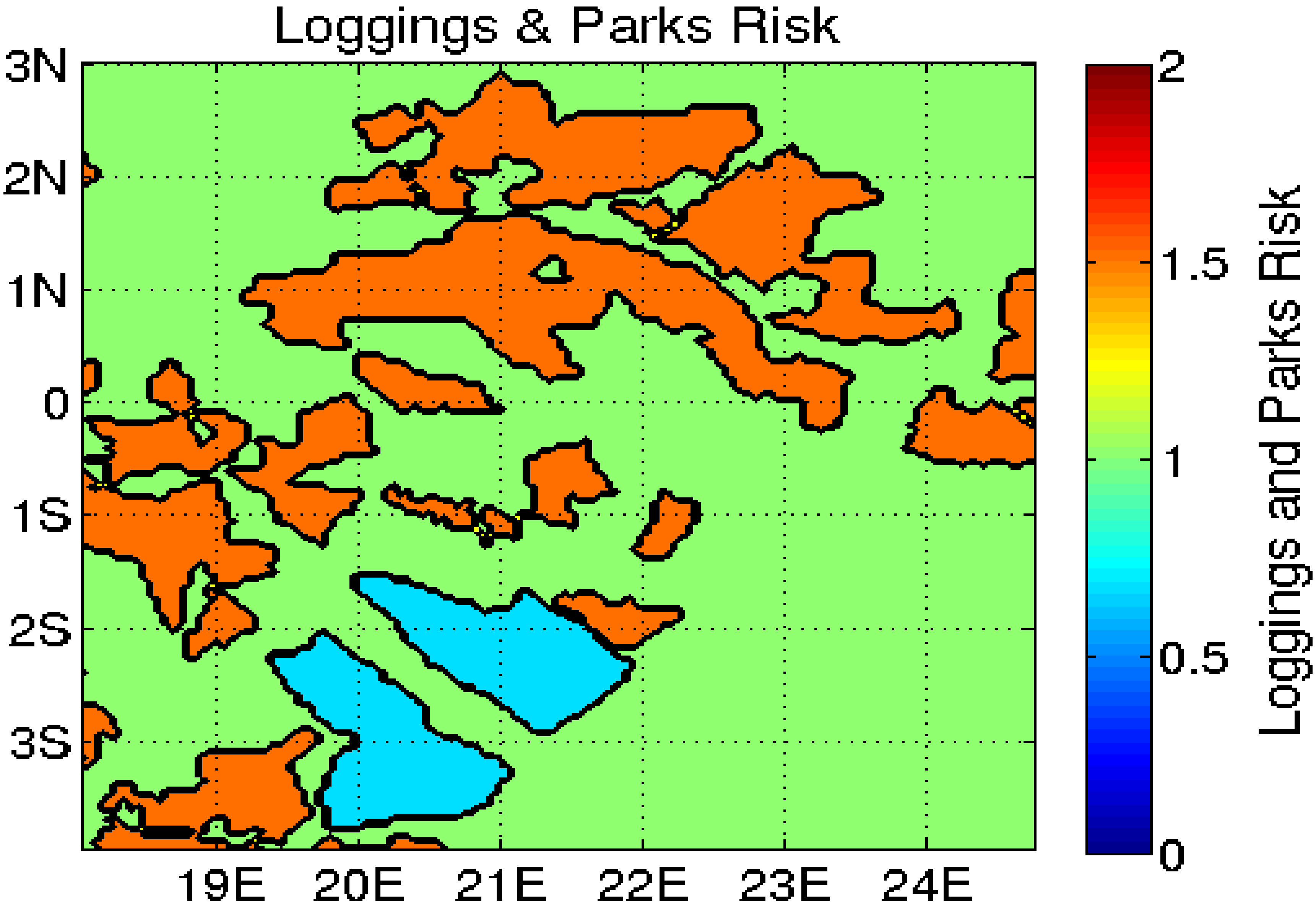
**1-2: $r_{park}$ and $r_{log}$**

$r_{park}$=0.66 inside parks
$r_{park}$=1.0 outside
$r_{log}$=1.5 inside log-conc
$r_{log}$=1.0 outside

- This would imply that policy enforcement results in a deforestation rate 2 times lower within parks in macro region in question.
- Likewise, $r_{log}$ would have a value exceeding 1.0



# Parks and logging Risk

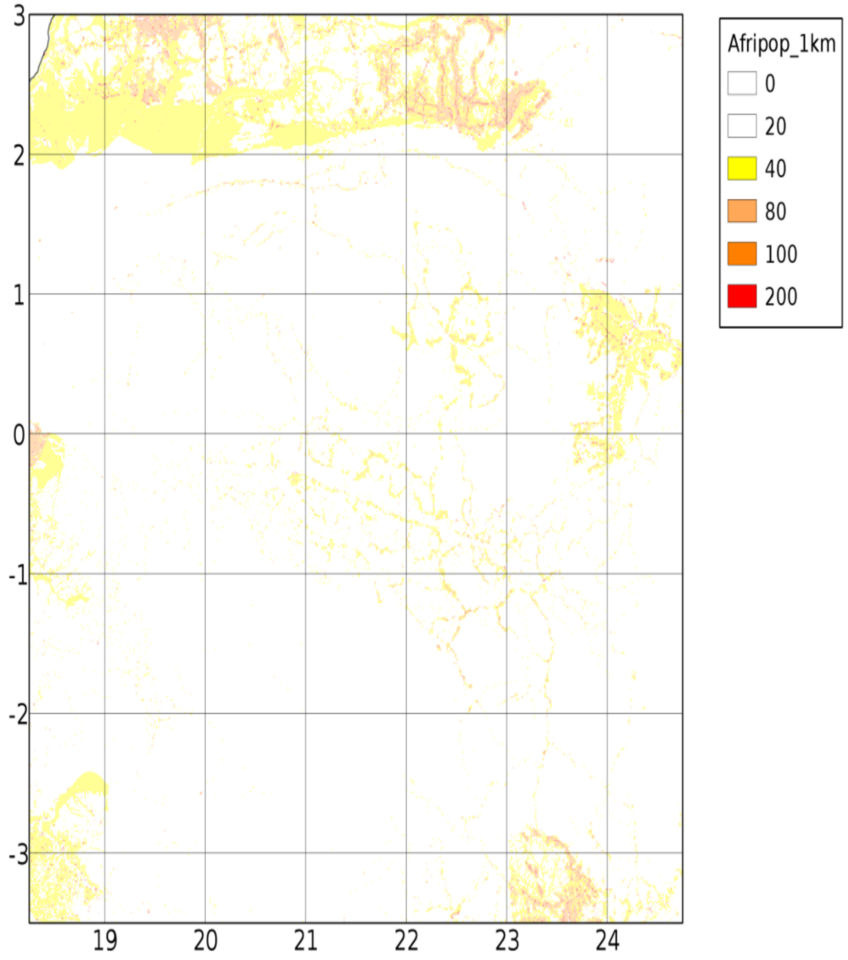


# Population

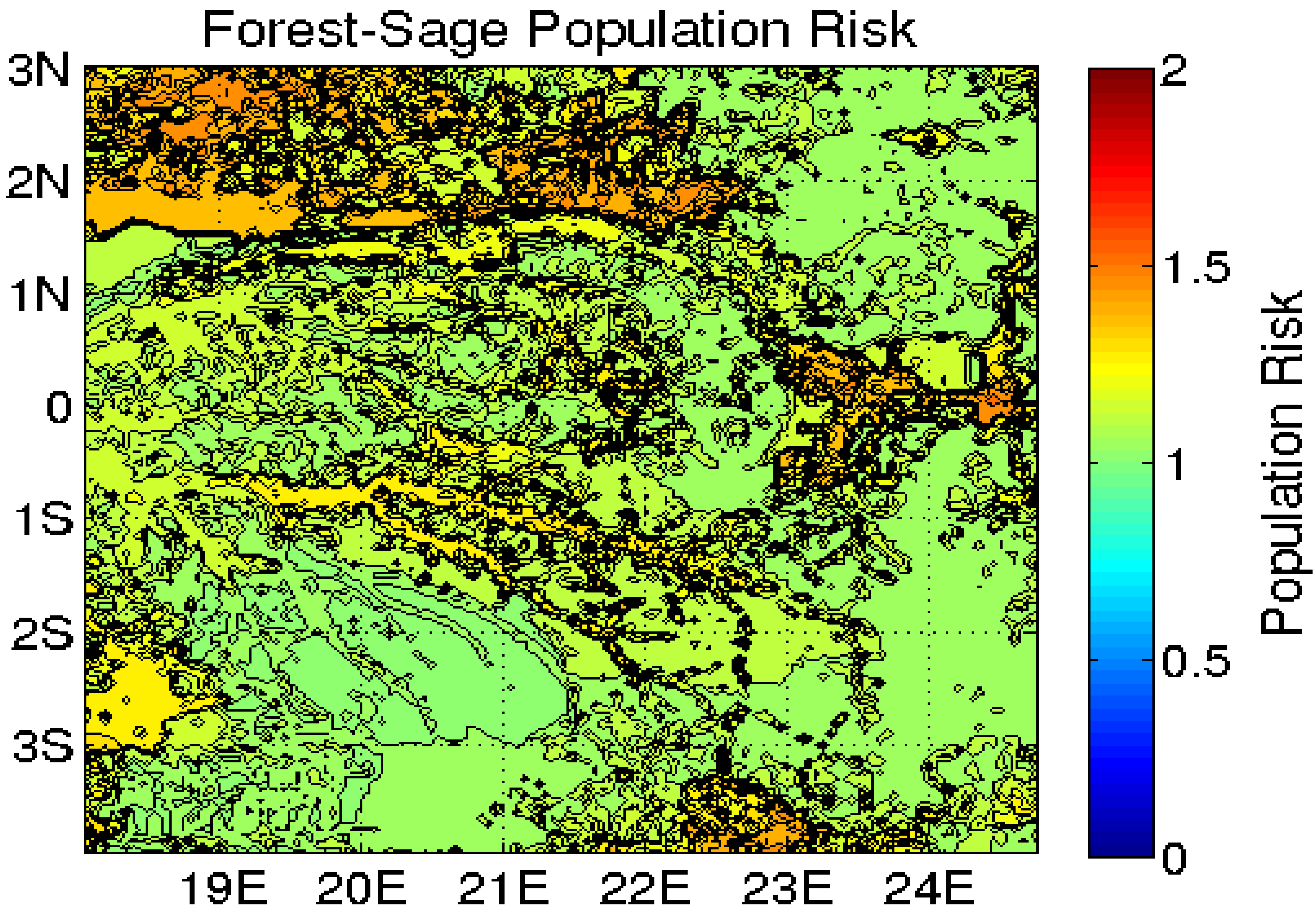
**3: $r_{pop}$**

$$r_{pop} = (K_{pop} - 1) * (1 - exp\left(-\frac{\overline{p}}{\tau_d}\right)) + 1 \quad (1)$$

- $Kpop$ is the "importance" of the population risk (set to 1.5)
- $\tau_d$ is the e-folding increase with population and set to 8 inabitants. (Celine 2013 Global change biology)
- $\overline{p}$ is the weigthed population
- Any evolution of the population is taken into account



# Population Risk

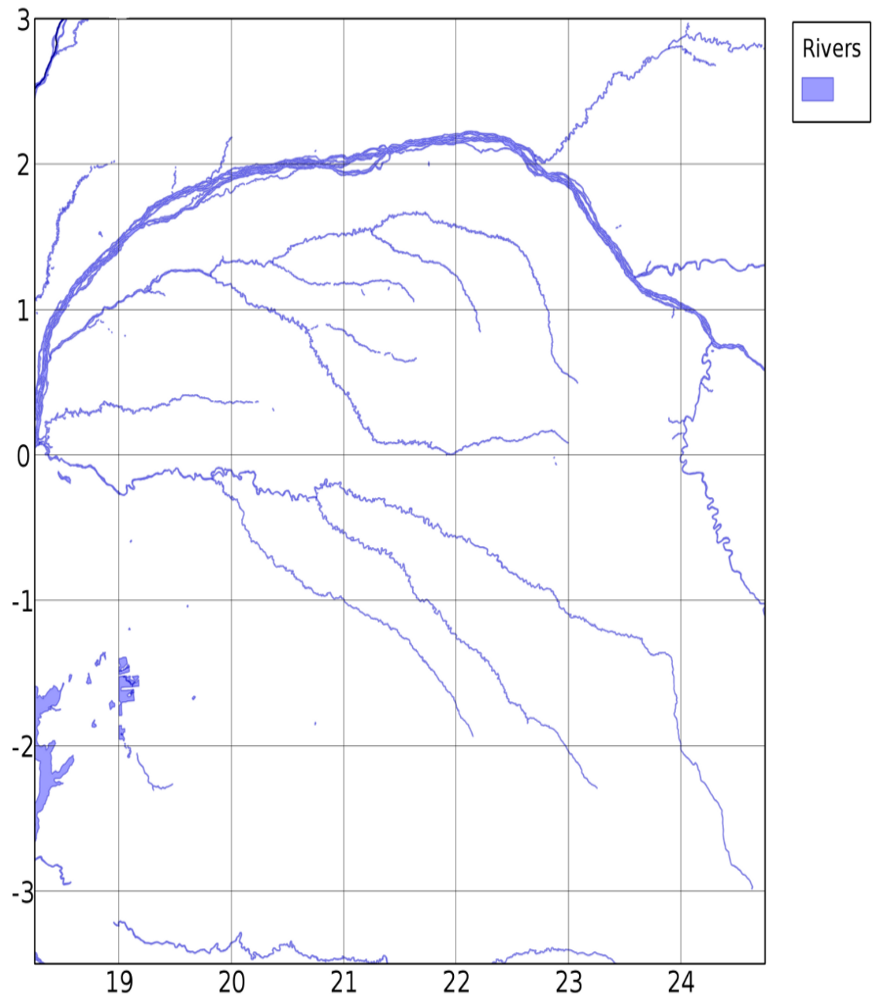


# Rivers

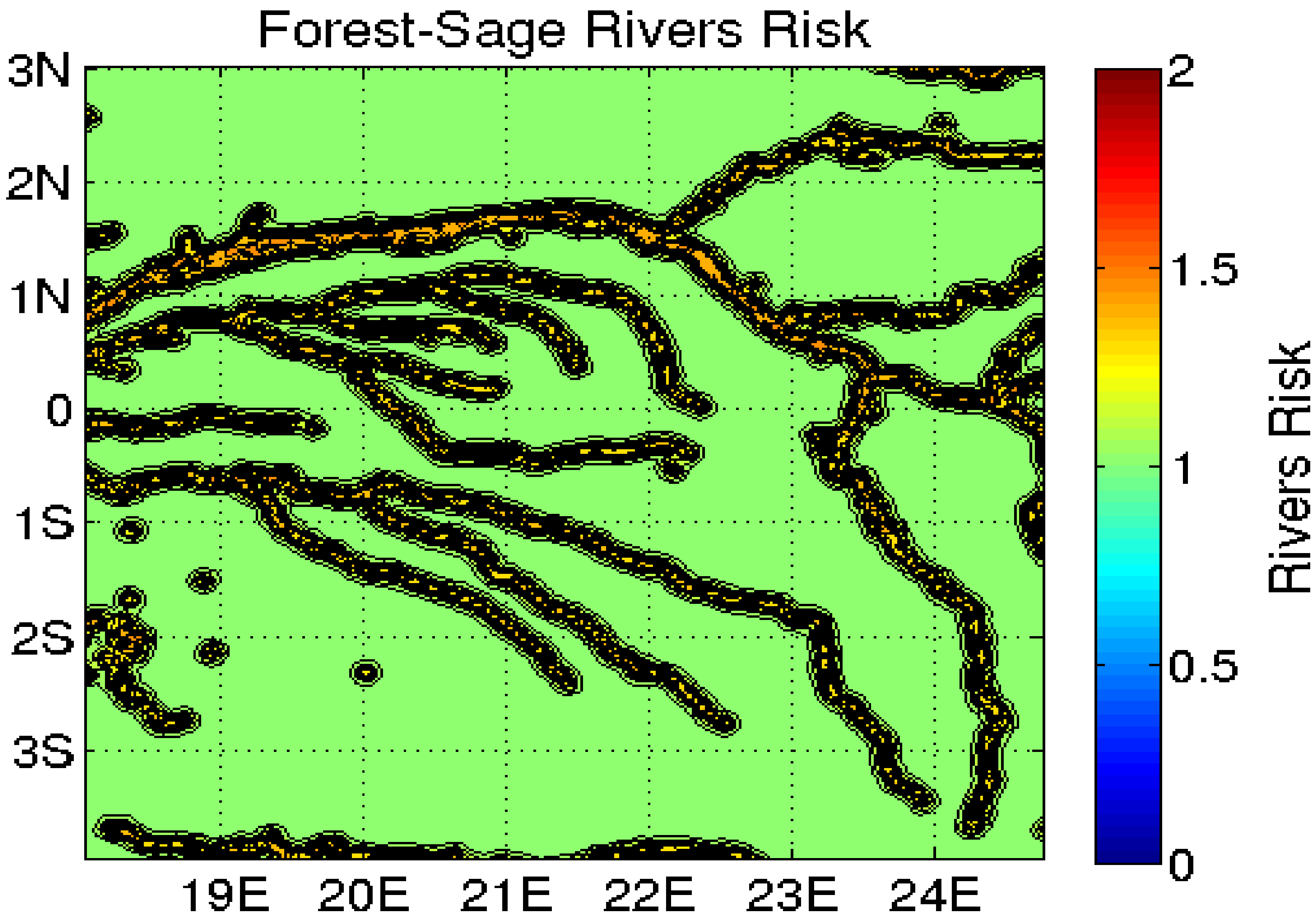
**4:** $r_{river}$

$$r_{river} = (K_{riv} - 1) * exp\left(-\frac{d_{river}}{\tau_{river}}\right) + 1 \quad (2)$$

- Rivers provide an easier access to the forest (Rogers 2011. Tech report)
- $Kriv$ is the "importance" of the river risk (set to 1.5)
- $\tau_{river}$ is the e-folding drop with distance and set to 10 km.(according to the efolding of the roads)



# Rivers Risk



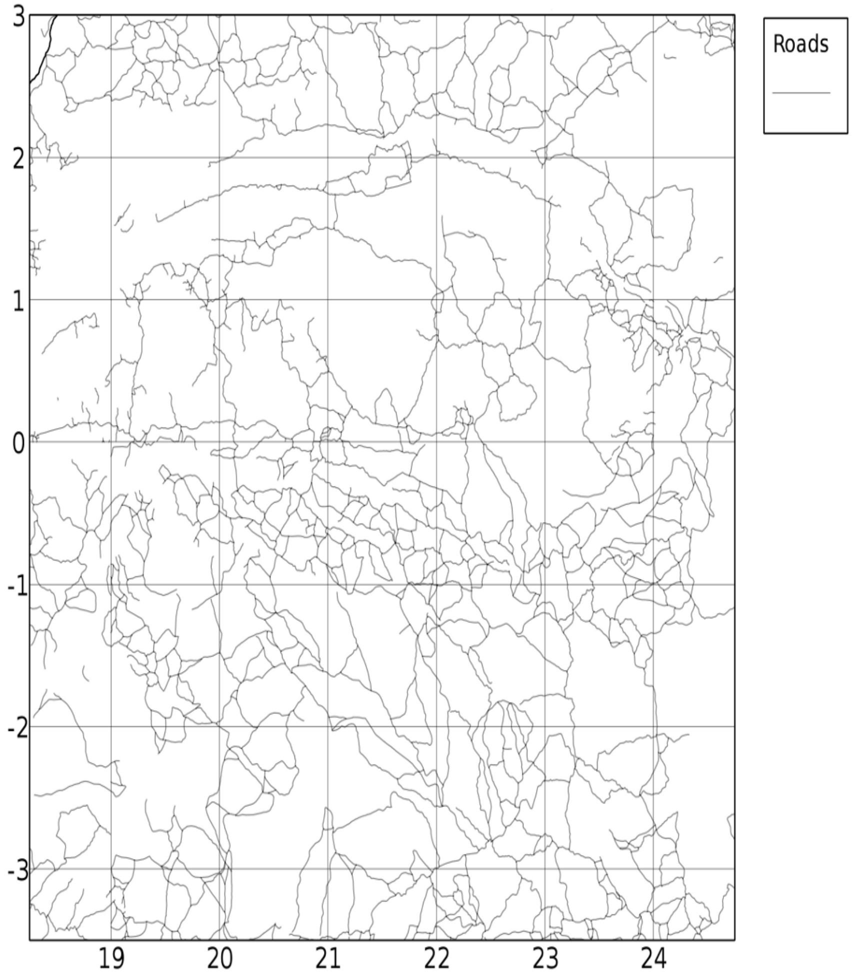
Forest-Sage Rivers Risk
3N
2N
1N
0
1S
2S
3S
19E
20E
21E
22E
23E
24E
2
1.5
1
0.5
0
Rivers Risk

# Roads

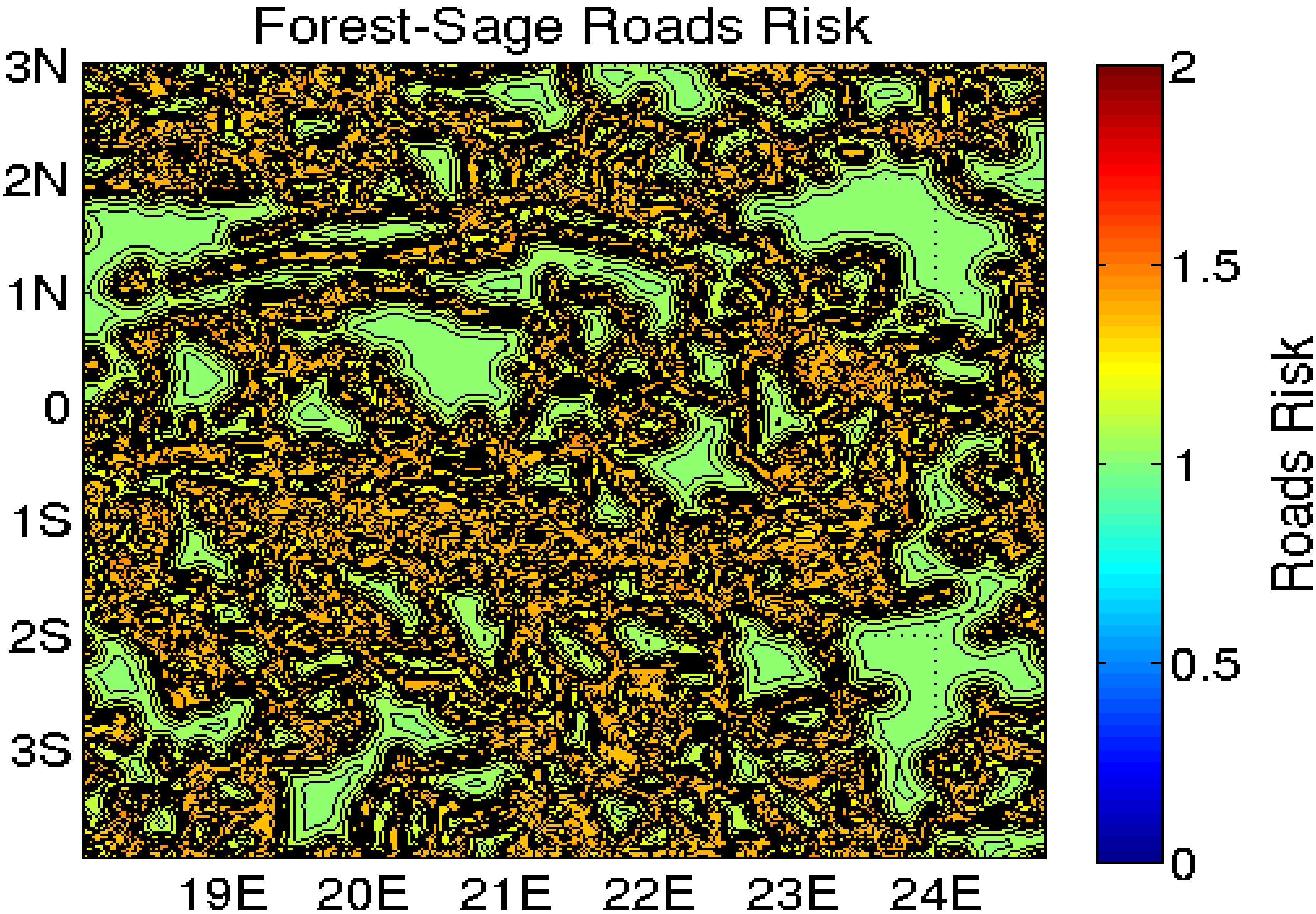
**5:** $r_{roads}$

$$r_{road} = (K_{roads} - 1) * exp\left(-\frac{d_{road}}{\tau_{road}}\right) + 1 \quad (3)$$

- Roads as the rivers provide an easier access to the forest (Amazon 60')
- *Kroad* is the "importance" of the roads risk (set to 1.5)
- $\tau_{road}$ is the e-folding drop with distance and set to 10 km. (Ferraz 2009 Forest Ecology and management 257, 1586-1595 )



# Roads Risk

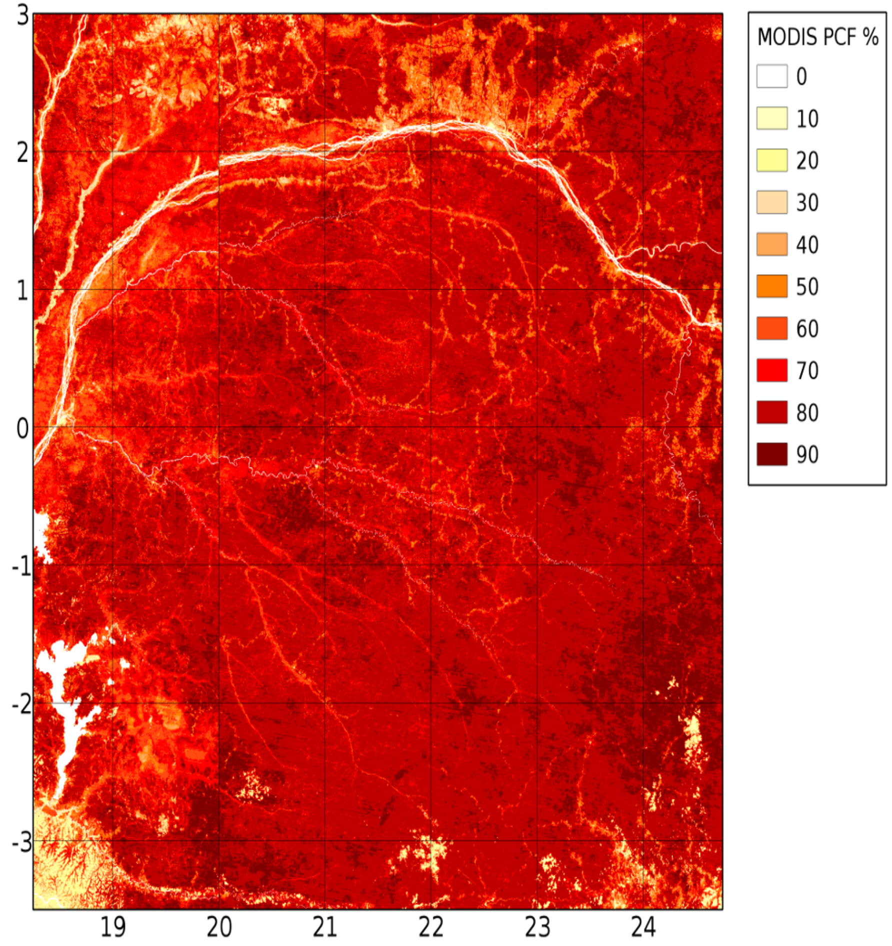


Forest-Sage Roads Risk
3N
2N
1N
0
1S
2S
3S
19E
20E
21E
22E
23E
24E
2
1.5
1
0.5
0
Roads Risk

# Fragmentation

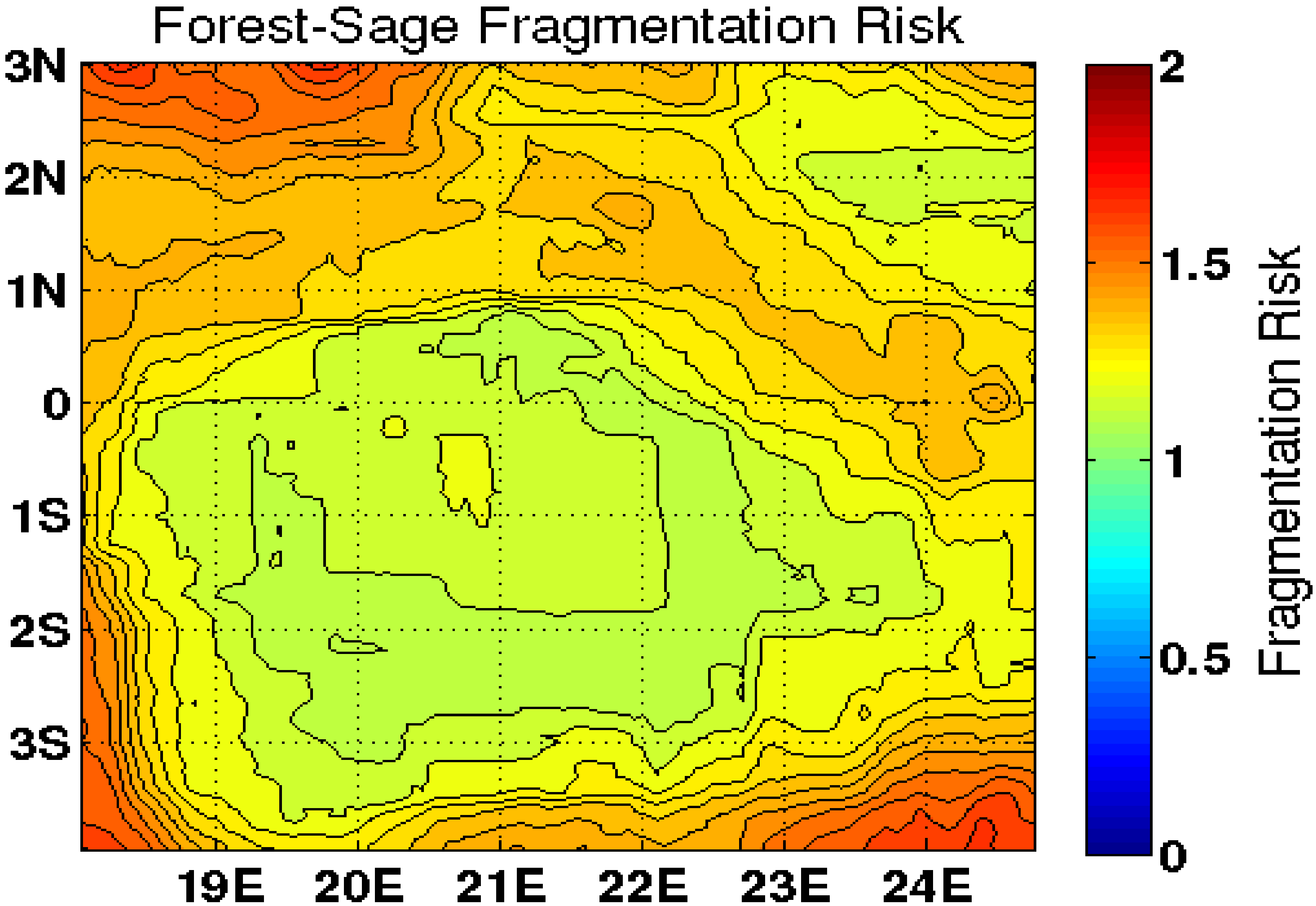
**6: $r_{tree}$**

$$r_{treee} = (K_{tree} - 1) * (std_{tree} / K_{tree}) + 1 \quad (4)$$




- The fragmentation is derived by looking at the inhomogeneity of the forest cover
- $K_{tree}$ is the importance of the fragmentation and set to 1.5
- $std_{tree}$ is normalized by $K_tree$

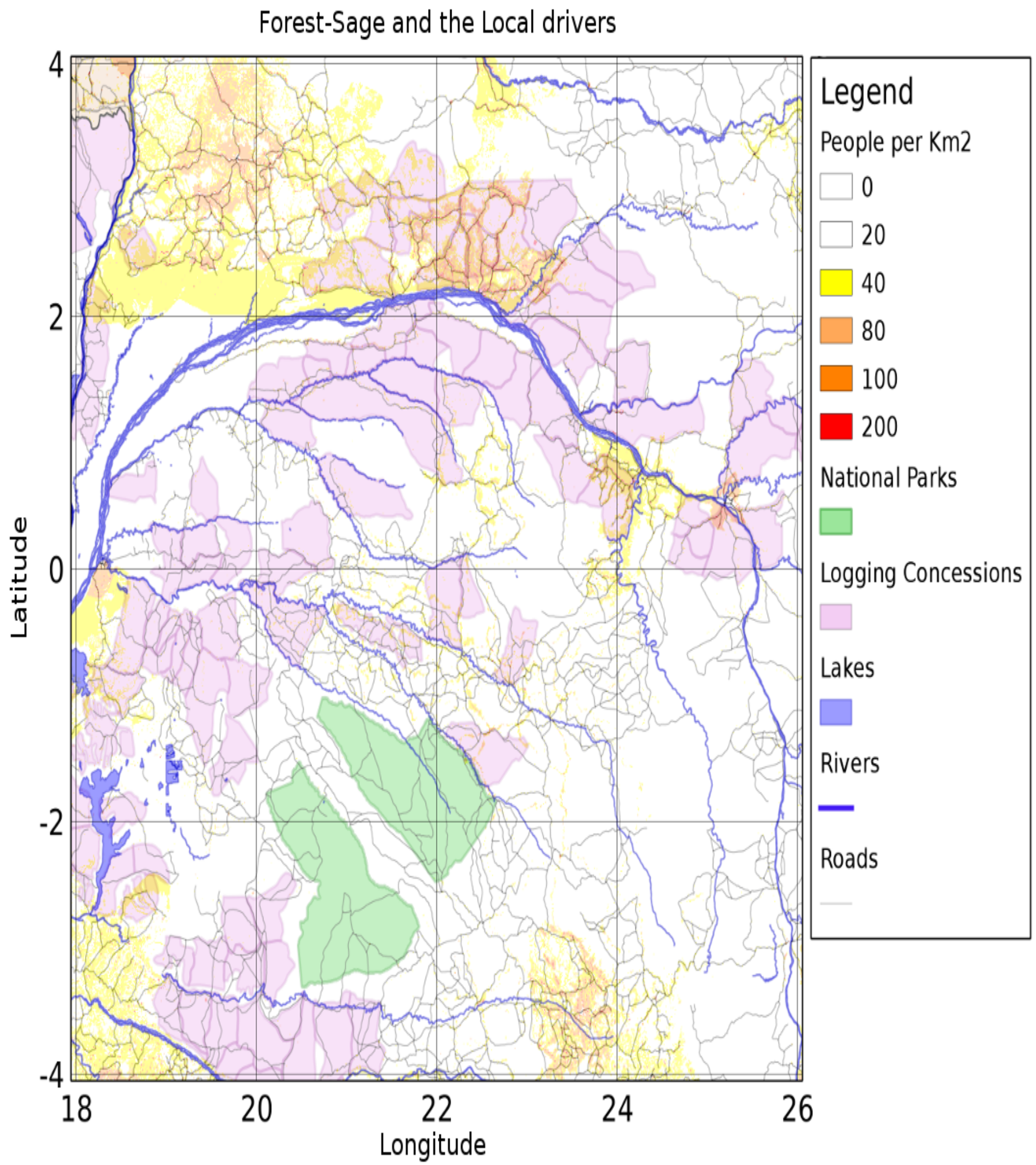
# Fragmentation Risk



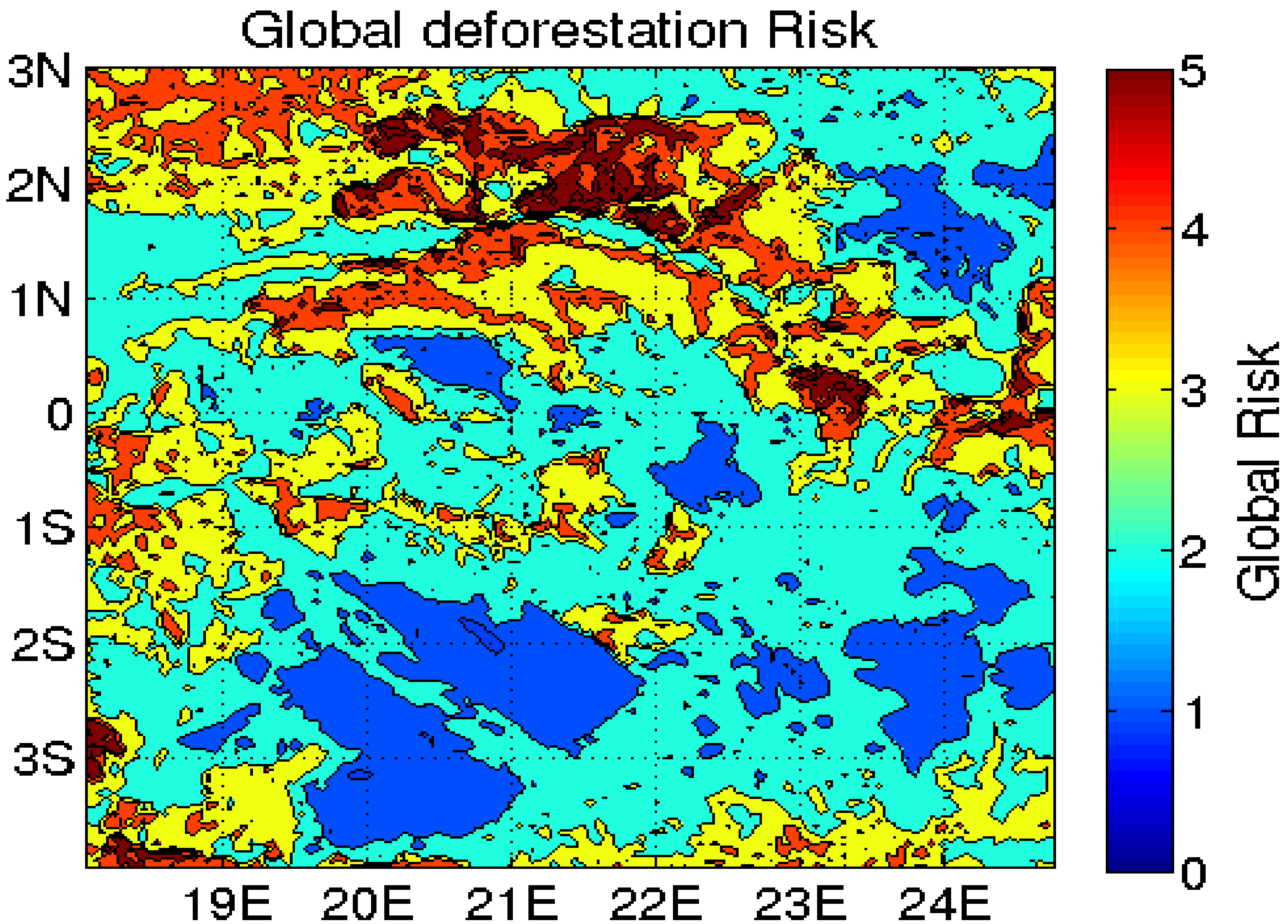
# Global Risk

**6:** $r_{global}$

$$r_{global} = \sum_{i=1}^{n} \prod_{j=1}^{n} r_j \quad (5)$$



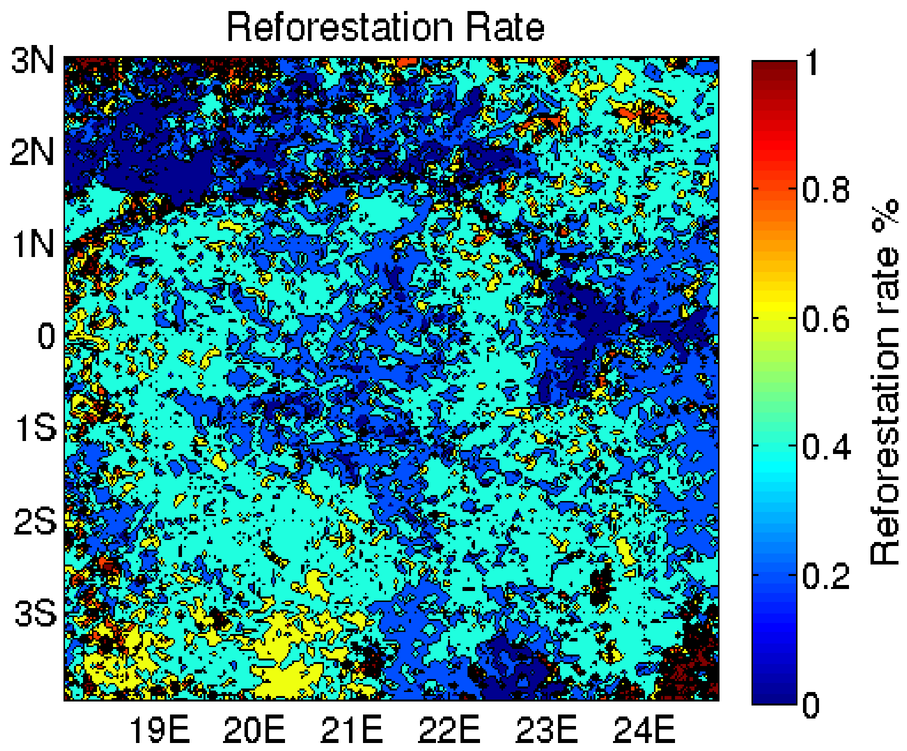
# Global Risk



Global deforestation Risk
3N
2N
1N
0
1S
2S
3S
19E
20E
21E
22E
23E
24E
5
4
3
2
1
0
Global Risk

# Reforestation Rate

## Reforestation Rate




## Reforestation Rate

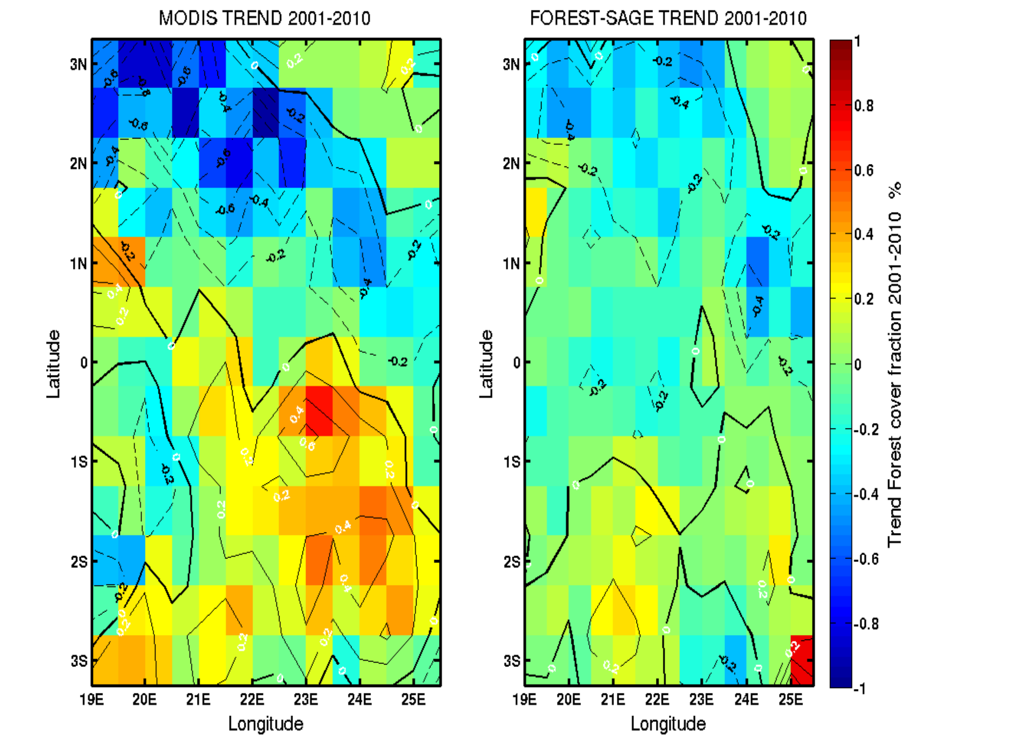
$$Ref = (pft_{target} - pfti/\tau f) \quad (6)$$

$$pft_{target} = max_{pft} * exp^{-wgt_{pop}/100} \quad (7)$$

- Stochastic Process
- Related to the vegetation cover and moduled by population density
- It can offset the deforestation rate
- to be correlated with potential vegetation map (Ramankutty and Foley)

# MODIS-VCF vs FOREST-SAGE Preliminary Results

## Preliminary Validation




## Preliminary Results

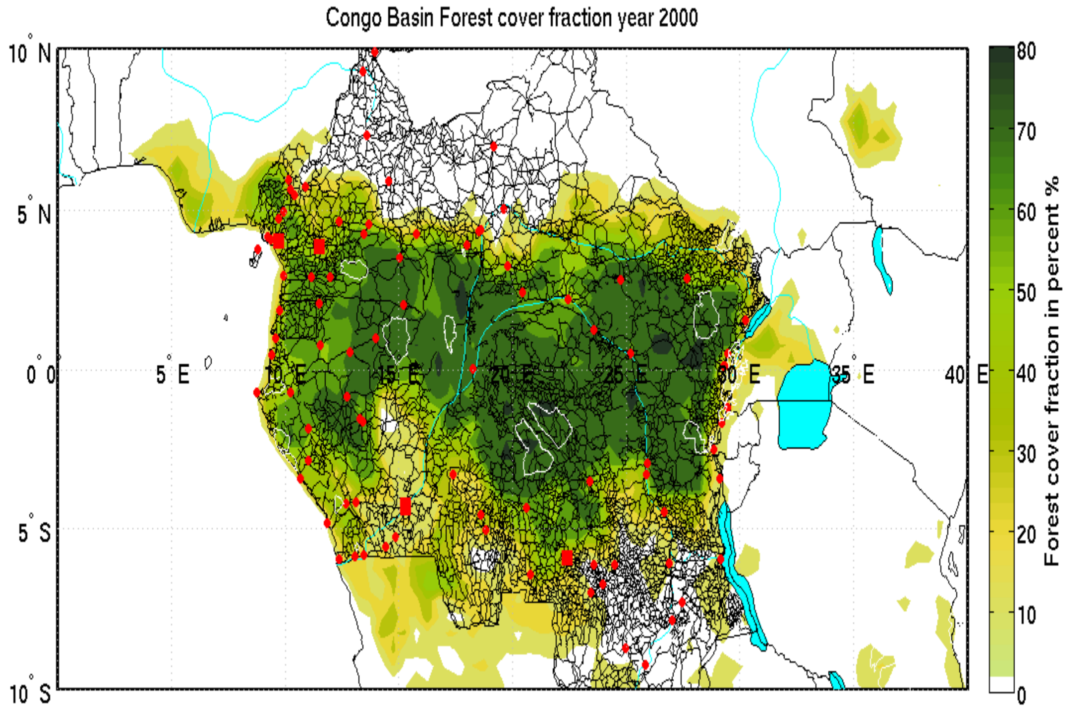
- $\frac{\partial f}{\partial t} = \frac{\partial f_{MODIS}}{\partial t}$
- The main spatial patterns are detected
- The FS signal is too weak
- More sensitivity tests are required (ensemble)

$$\frac{\partial f}{\partial t} = \frac{\partial G}{\partial t} + \frac{\partial R}{\partial t} \tag{8}$$

# Future Runs

**Experiment set up**

- Test CLM 3.5 2000-2040 Preliminary test
- $\frac{\partial f}{\partial t} = 1\% year^{-1}$
- No Reforestation rate
- Multiple runs are required



# Conclusions

**FOREST-SAGE: a new dynamical model for generating deforestation and land-use scenarios**

- It can be initialazed with a wide range of inputs/resolution
- Division between macro and micro scale drivers of deforestation
- Allows detection of nonlinear climate response, tippings points in climate
- Preliminary Validation against MODIS-VCF shows a good agreement
- Usefull tool for near land use scenario (Population/roads are static)

## FOREST-SAGE: Future work

- Climate investigation with ensembles of scenarios and considering other regions (AR5)
- Implementing the slope/potential vegetation matrix
- FOREST-SAGE integrated with fully interactive vegetation mode
- Improved specification of macro-scenarios from socio-economic models
- Potential to link to other impacts models in a grand impacts suite with the links of water and population
- Link to other Land models