MELANOBS workshop – Noumea, April 2024

–ForestAtRisk–
Spatial forecasting of forest cover change in the humid tropics over the 21st century

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Plan

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   - Alternative scenarios
   - Other perspectives

Tropical deforestation

SCIENCE ADVANCES | RESEARCH ARTICLE

ENVIRONMENTAL STUDIES

Long-term (1990–2019) monitoring of forest cover changes in the humid tropics

C. Vancutsem[1]*, F. Achard[1], J.-F. Pekel[1], G. Vieilledent[1,2,3,4], S. Carboni[5], D. Simonetti[1], J. Gallego[1], L. E. O. C. Aragão[6], R. Nasi[7]

Vancutsem et al. 2021, *Science Advances*, doi :10.1126/sciadv.abe1603

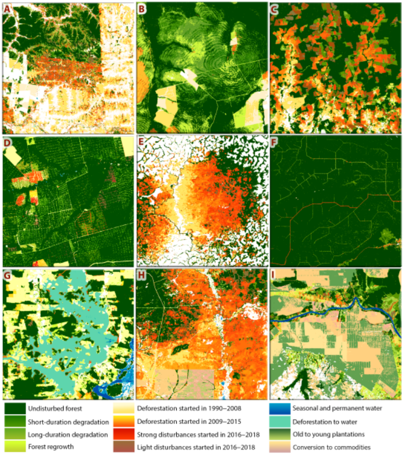
- Tropical Moist Forest (TMF)
- 1990–2019 : Annual deforestation, degradation, regeneration

Tropical deforestation

- Full Landsat archive (1982–2019), 30m pixel, time-series analysis
- Classification tree based on expert knowledge
- Tropical deforestation was underestimated (-33% in 2000–2012, Hansen et al. 2013)
- Maps and data : https://forobs.jrc.ec.europa.eu/TMF/

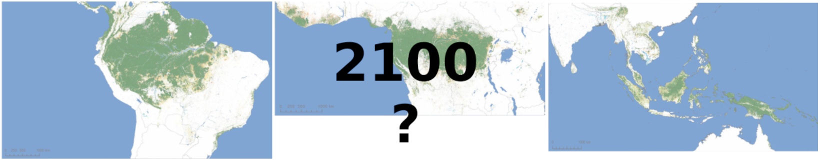
Tropical deforestation

- Precise enough to visually identify the causes of deforestation (logging, fires, agriculture)



Forecasting deforestation

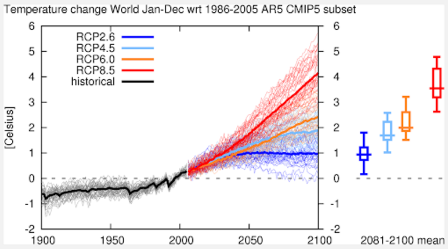
- About 7 Mha of tropical moist forest are disappearing each year (size of Ireland)
- At this rate, will tropical forests still exist in 2100 ?
- If yes, where will they be located ?
- What will be the consequences of future deforestation on biodiversity and carbon emissions ?



Forecasting deforestation

Why is it a timely question ?

- **Alert** decision makers
- Carbon emissions scenarios ($\rightarrow$ IPCC)
- Biodiversity scenarios ($\rightarrow$ IPBES)
- Local scale : systematic conservation planning (protected area network, REDD+)
- Modelling $\rightarrow$ main spatial drivers of deforestation

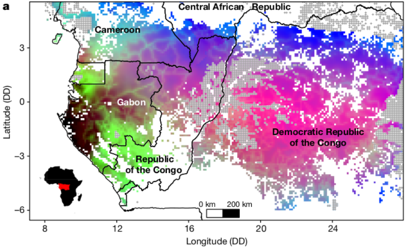


Elevation des températures pour les 4 grands scénarios du GIEC. Source : KNMI.

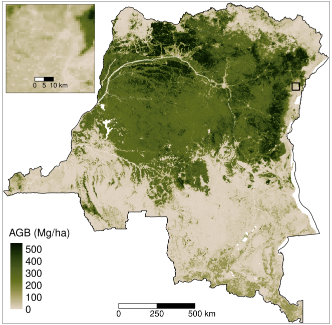
IPCC scenarios

Forecasting deforestation **spatially**

Why is **spatial** forecasting important ?
Because both biodiversity and carbon stocks vary strongly in space.



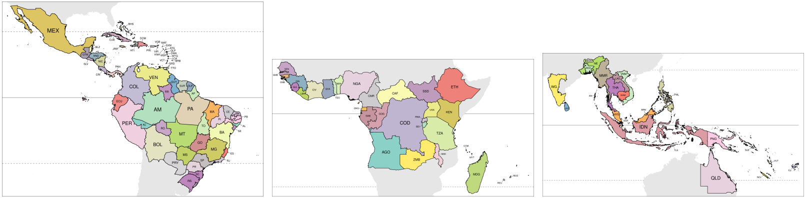
Community map
(Réjou-Méchain 2021)



AGB map in DRC

Approach

- **i.** Consider tropical moist forest in **92** countries (119 study areas)
- **ii.** Estimate the current deforestation rate and uncertainty in each country
- **iii.** Model the spatial risk of deforestation from environmental factors
- **iv.** Forecast the deforestation assuming a business-as-usual scenario
- **v.** Consequences in terms of biodiversity and carbon emissions



The 119 study areas in the 3 continents

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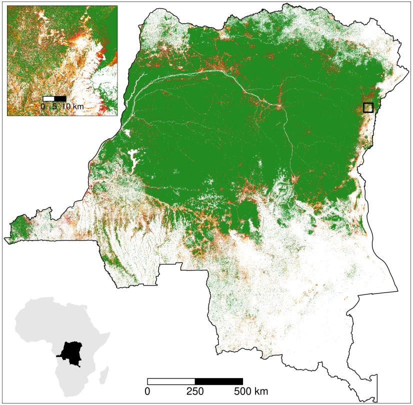
Modelling the intensity of deforestation

- 10 values of annual deforested area (ha/yr) in 2010–2020 per country
- (Brazil : per state, India : per region)
- Mean deforestation rate (ha/yr) in 2010–2020 per country
- Uncertainty around the mean (95% confidence interval)



Past deforestation 2000–2010–2020 in DRC

Modelling the intensity of deforestation

Country – study area	fc2010 (Kha)	fc2020 (Kha)	d (ha/yr)	d' (ha/yr)	d'' (ha/yr)
America					
Antigua and B.	4	3	55	24	87
Bahamas	122	103	2,044	1,013	3,075
Barbados	4	3	73	21	125
Belize	1,337	1,206	12,735	7,865	17,605
Bolivia	30,657	28,671	203,506	127,518	279,493
Brazil – Acre	13,292	12,824	48,076	41,217	54,936
Brazil – Alagoas	100	89	1,196	730	1,663
Brazil – Amapa	11,589	11,457	14,934	11,766	18,101
Brazil – Amazonas	146,956	145,361	164,083	117,648	210,518

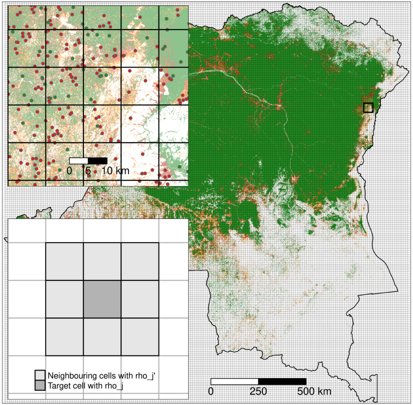
Examples of mean deforestation rate with uncertainty

Modelling the spatial risk of deforestation

A logistic regression model with iCAR process

$$y_i \sim \mathcal{B}ernoulli(\theta_i)$$
$$\text{logit}(\theta_i) = \alpha + X_i\beta + \rho_{j(i)}$$
$$\rho_{j(i)} \sim \mathcal{N}ormal(\sum_{j'} \rho_{j'}/n_j, V_\rho/n_j)$$

(NB : We compared this model with a simple GLM and a Random Forest model using a cross-validation procedure)



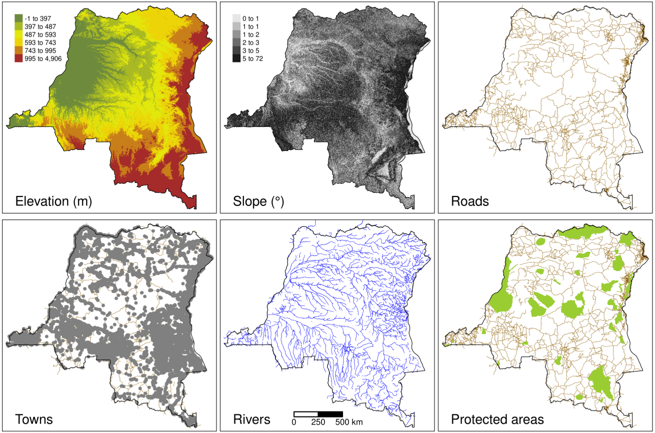
Square grid of 10km cells over DRC

Spatial variables

- Height explanatory variables

Product	Source	Variable derived	Unit	Resolution (m)	Date
Forest maps (2000-2010-2020)	Vancutsem et al. 2021	distance to forest edge	m	30	–
		distance to past deforestation	m	30	–
Digital Elevation Model	SRTM v4.1 CSI-CGIAR	elevation	m	90	–
		slope	degree	90	–
Highways	OSM-Geofabrik	distance to road	m	150	March 2021
Places		distance to town	m	150	March 2021
Waterways		distance to river	m	150	March 2021
Protected areas	WDPA	presence of protected area	–	30	March 2021

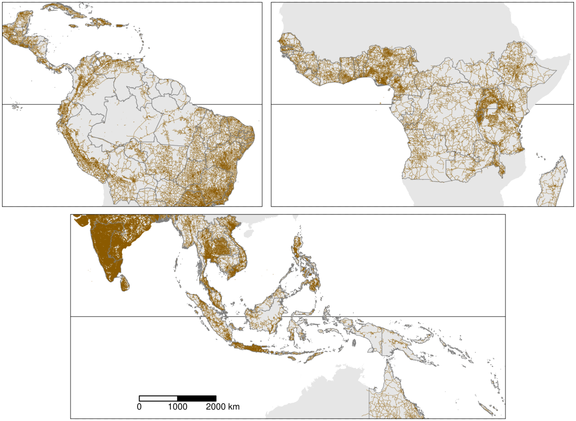
Spatial variables



Spatial explanatory variables in DRC

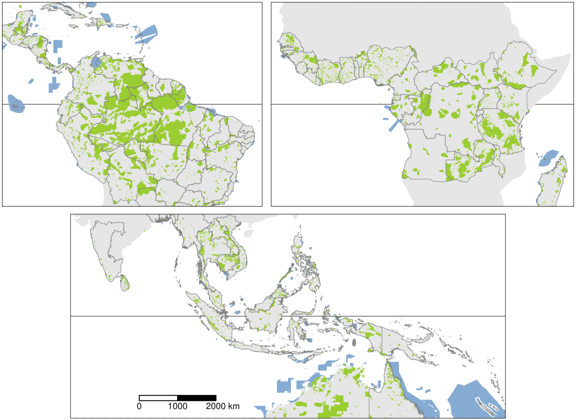
Roads

- OpenStreetMap (OSM)
- "motorway", "trunk", "primary", "secondary" and "tertiary" roads
- 3.6 million roads from OSM



Protected areas

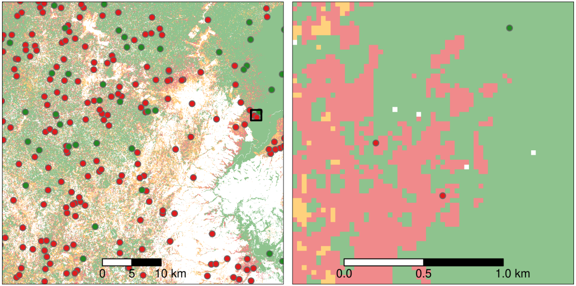
- PA status : "Designated", "Inscribed", "Established", or "Proposed" before 1st January 2010
- 85,000 protected areas from WDPA



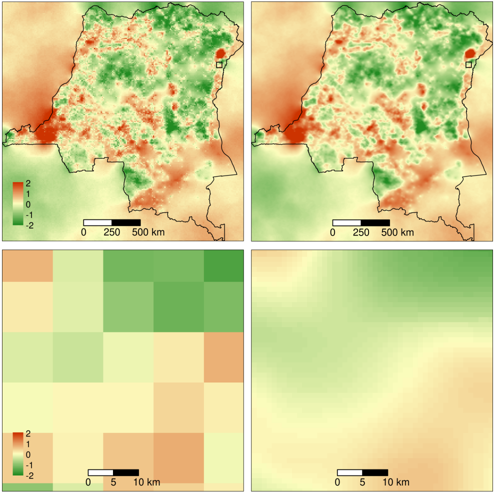
Sampling

One word on sampling :

- Stratified sampling between deforested/non-deforested pixels in 2010–2020
- Total number of points proportional to the forest cover in 2010 (from 20,000 to 100,000 points per study area)
- Huge data-set of 3.2 M forest pixels (~288 Kha of forest)



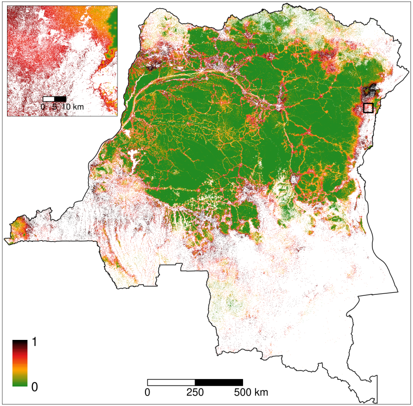
Spatial random effects



Interpolation of spatial random effects at 1km in DRC

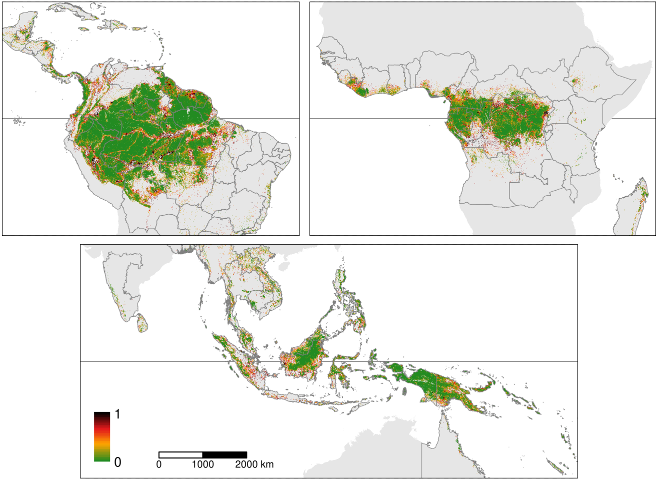
Spatial probability of deforestation

We use the fitted model to compute the spatial probability of deforestation.



Relative spatial probability of deforestation in DRC for the year 2020

Spatial probability of deforestation

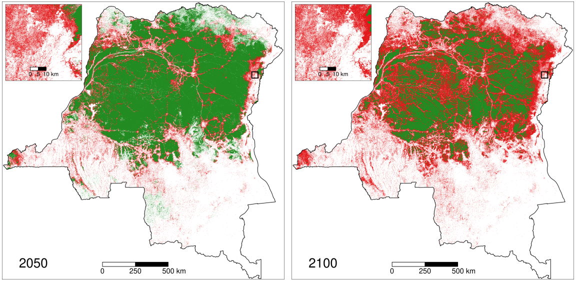


Pantropical map of the spatial probability of deforestation

https://forestatrisk.cirad.fr/maps.html

Future forest cover

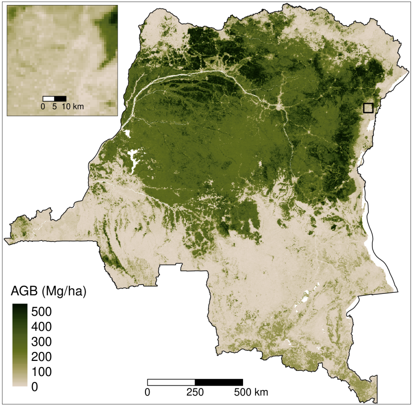
- Total deforested area D (ha) in a given period of time Y (yr) : $D = d \times Y$, with d the annual deforested area (ha/yr).
- Number of pixels to be deforested : $n = D/0.09$, 0.09 ha being the pixel area.
- The n pixels with the highest deforestation probabilities are considered deforested in that period of time.



Projected deforestation in 2020–2050 and 2020–2100 in DRC

Future carbon emissions

- Projected deforestation for years 2030, 2040, . . ., 2100.
- We combine the maps of the projected deforestation with the (2000–2010) forest carbon map by Avitabile 2016 GCB (1km resolution).



Aboveground biomass in DRC

Software

- `forestatrisk` Python package
- Process large rasters by blocks
- Several statistical models : iCAR, GLM, RF, etc.
- Set of functions for sampling, modelling, forecasting, validating

`forestatrisk` Python package

python 2 | 3 · pypi v1.0 · PyPkg passing · licence GPLv3 · DOI 10.5281/zenodo.996337 · JOSS 10.21105/joss.02975

Website : https://ecology.ghislainv.fr/forestatrisk
Article : **Vieilledent** 2021, *JOSS*, doi : 10.21105/joss.02975

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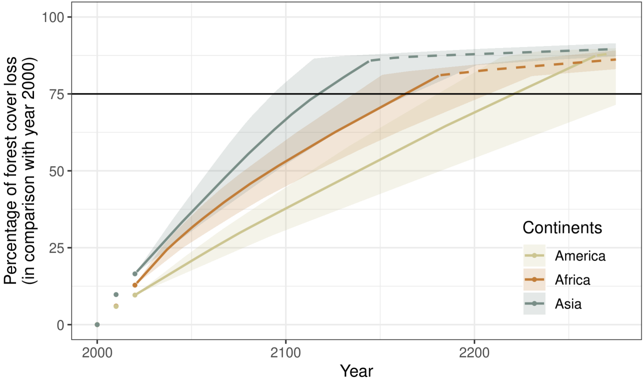
Tropical forest cover loss

75% of the tropical forest existing in 2000 will be lost in 2120, 2160, and 2220 in Asia, Africa, and America, respectively (average uncertainty of ±45 years).



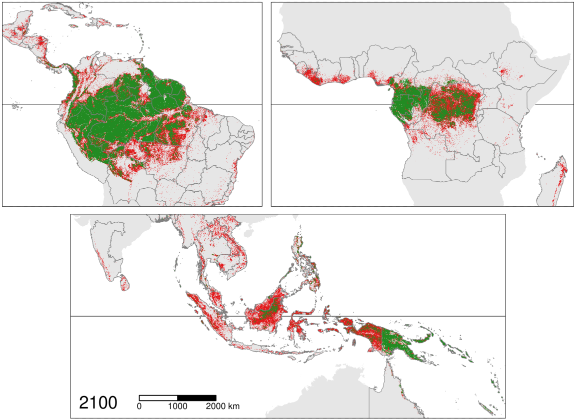
Tropical forest cover loss

- 20 countries, 5 states in Brazil, and 1 region in India (having > 1 Mha of forest in 2020) will lose all their tropical forest by 2100.
- No more tropical forests in 6 biodiversity hotspots (extinction of 29,140 endemic species of plants and 4,576 species of vertebrates).

Regions	fc2000 (Kha)	fc2010 (Kha)	fc2020 (Kha)	d (Kha/yr)	p (%/yr)	fc2050 (Kha)	fc2100 (Kha)	loss21 (%)	yr75
Countries									
Brazil	375,893	349,784	334,982	1,537	0.4	288,862	211,996	44	2183
DRC	131,621	126,164	117,812	860	0.7	92,007	48,999	63	2114
Indonesia	141,262	127,699	116,317	1,215	1.0	79,853	19,078	86	2087
Continents									
America	690,358	648,928	621,160	2,893	0.5	534,552	404,344	41	2197
Africa	275,745	259,667	238,791	2,176	0.9	180,848	115,591	58	2143
Asia	301,412	270,679	246,894	2,533	1.0	171,417	66,034	78	2094
All cont.	1,267,515	1,179,273	1,106,845	7,602	0.7	886,816	585,968	54	2171

Pantropical map of the future forest cover

Tropical forests in 2100 will be (i) highly fragmented, (ii) concentrated in remote areas (far from roads and towns), pref. in protected areas, and at high elevations.

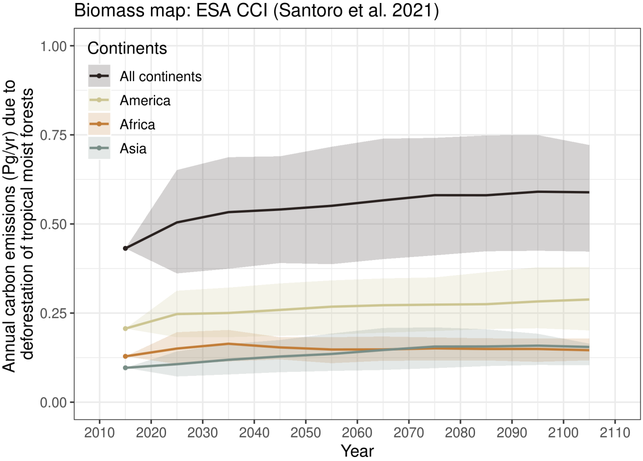


Pantropical map of future forest cover in 2100

https://forestatrisk.cirad.fr/maps.html

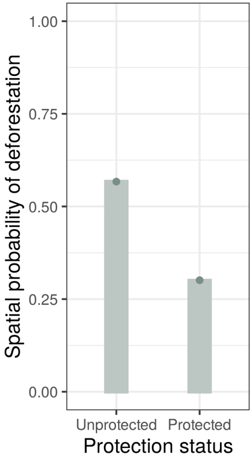
Carbon emissions

- Future deforestation will impact forests with higher carbon stocks
- Annual carbon emissions will increase from 0.525 Pg/yr in 2010–2020 to 0.746 Pg/yr in 2070–2080 (42% increase)



Protected area effect

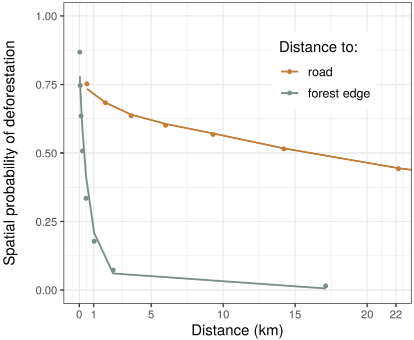
- Significant PA effect in 74 study areas out of 119 (88% of the TMF in 2010).
- PA reduce the risk of deforestation by 40%.



Effect of PA on the deforestation risk

Road effect

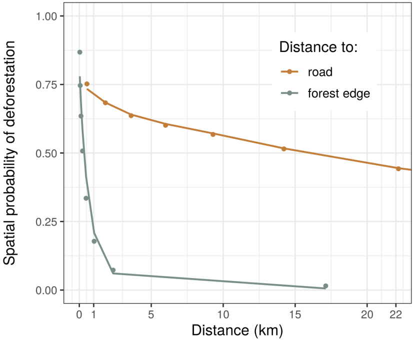
- Significant road effect in 59 study areas out of 119 (90% of the TMF in 2010).
- At 10km from a road, the risk of deforestation decreases by 13%.



Effects of roads and forest edge on the deforestation risk

Forest edge effect

- Road effect must be interpreted together with forest edge effect.
- At 1km from the forest edge, the risk of deforestation decreases by 93%.



Effects of roads and forest edge on the deforestation risk

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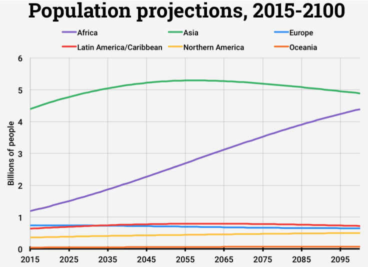
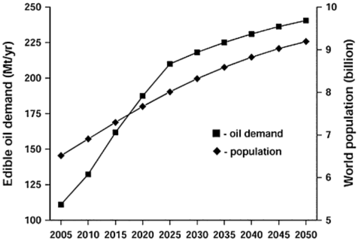
Uncertainty analysis

- Despite uncertainty, results are clear and alarming.
- "Business-as-usual" scenario $\neq$ what **will** happen in the future.
- "Business-as-usual" scenario $=$ in the absence of any change.
- The objective is to alert and create a momentum for change.
- Nonetheless, rather optimistic scenario.

Alternative scenarios : demography and demand

- Demography : in Africa, a large part of the population depends on slash-and-burn agriculture for their livelihood.
- Increasing demand for agricultural commodities : e.g., palm oil, Corley et al. 2009





Other perspectives

- Models can be refined locally (e.g., Ivory-Coast, Madagascar, New-Caledonia) with more information on the context.
- Very rough estimates of biodiversity loss : need for world biodiversity maps.
- (Fragmentation study, regeneration potential, etc.)

Mining activity in New-Caledonia

... Thank you for attention ...

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