Carbon storage estimation and possibilities for its marketing in community managed forests of Papua New Guinea

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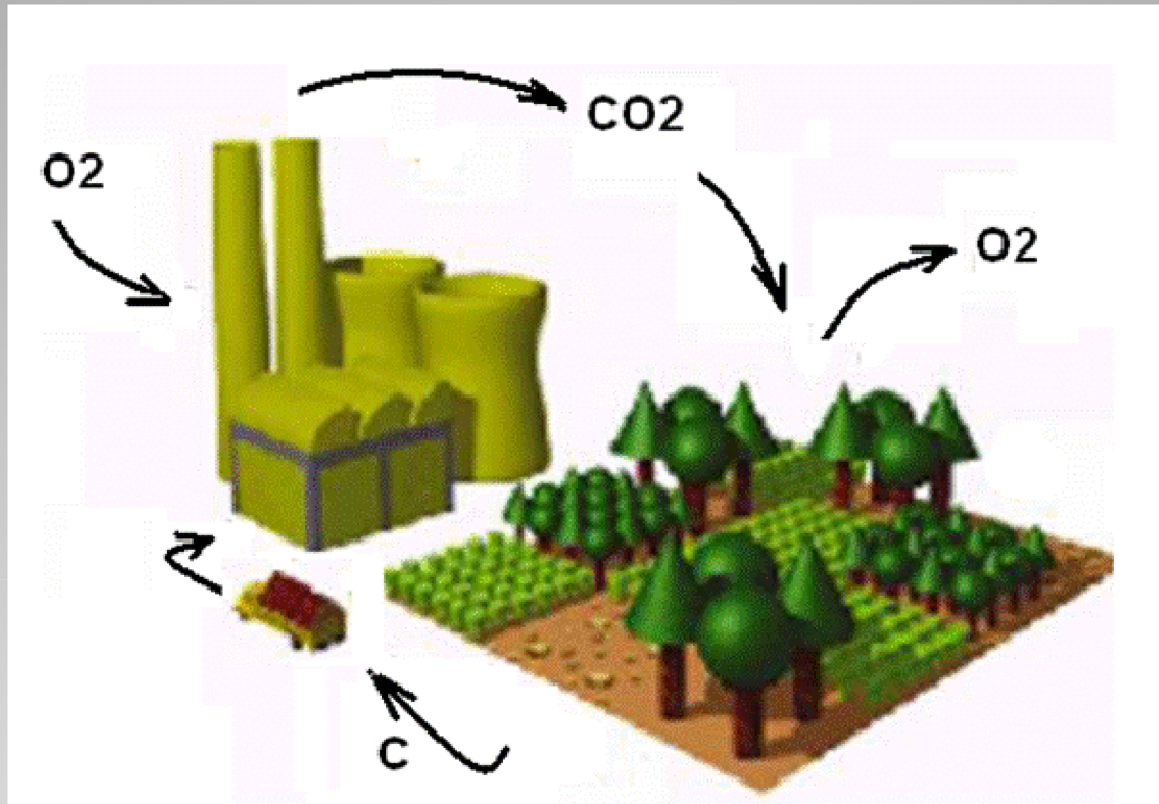
Global warming and its effects

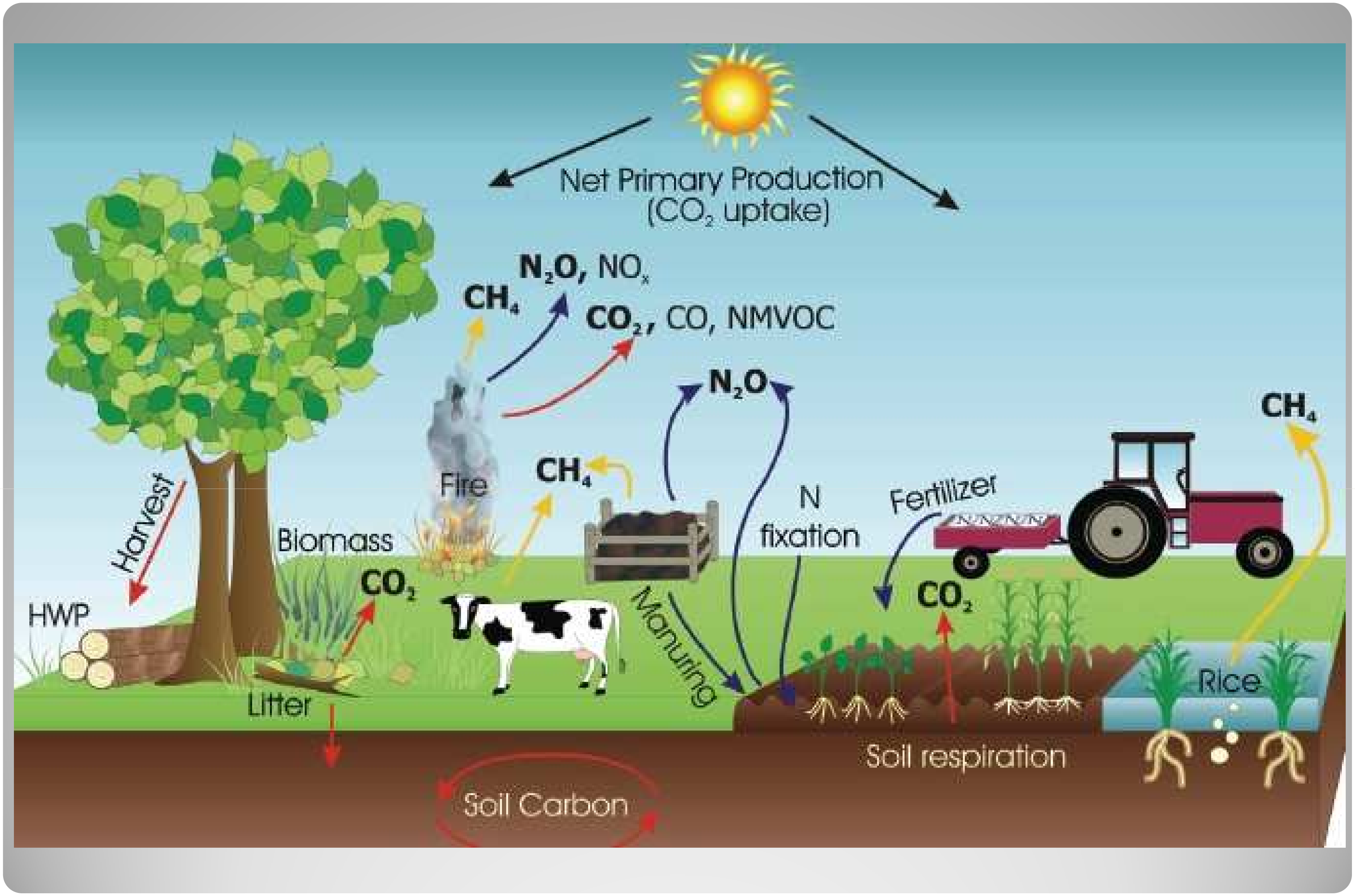
Caused by heat-trapping gases accumulation (acting as a “lid”) into the atmosphere faster than plants and oceans can soak them up. In geologic time ecosystem changes are coming in a nanosecond (within the span of a human life):

- CO_2 levels rise
- Precipitation increases
- Mercury climbs
- Ice thins
- Permafrost thaws
- Wildfires increase
- Lakes shrink
- Habitats change
- Diseases spread
- Amphibians disappear
- Cloud forest dry

Lakes freeze up later
Mountain streams run dry
Droughts linger
Spring arrives earlier
Autumn comes later
Plants flower sooner
Migration times vary
Birds nest earlier
Coral reefs bleach
Coastlines erode
Phytoplankton decline



Sustainably produced biomass is CO_2 neutral. Burning fossil fuels releases CO_2 locked up for millions of years. Burning biomass returns to the atmosphere CO_2 that was absorbed on plants growth. No net release of CO_2 if cycle of growth and harvest is sustained.



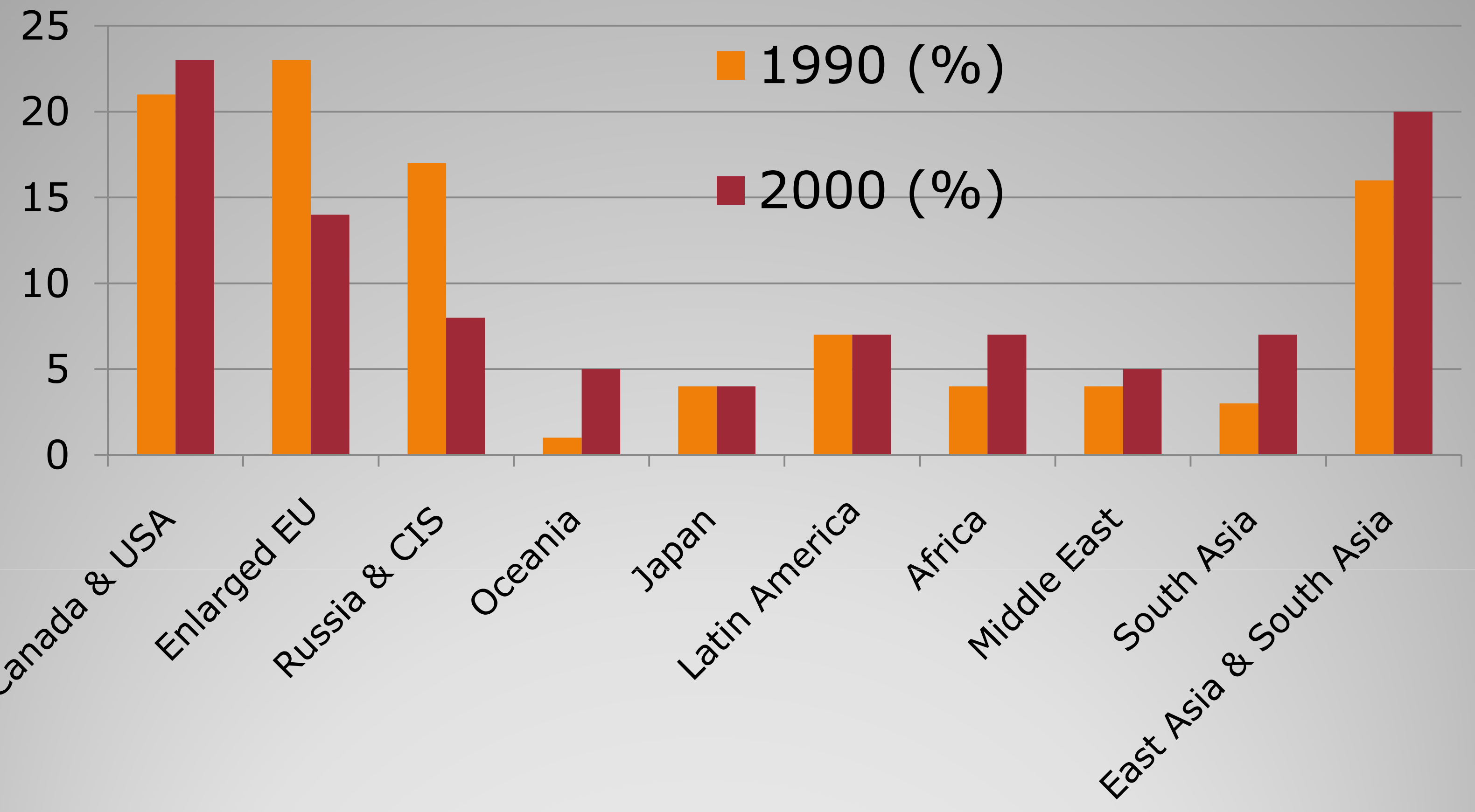
In 2000 year: CO_2 = 63%, CH_4 = 24%, N_2O (nitrous oxide) =10%, others = 3% of C equivalent emissions (IPCC, 2001).

Land cover change connection

- Release C/year from deforestation ⇨ 18-25% of global C emissions (Skutsch, et al. 2007; Stern Review, 2007).

  = 1.7 billion tons, more than the total emissions coming from the transport sector (Stern Review, 2007). .

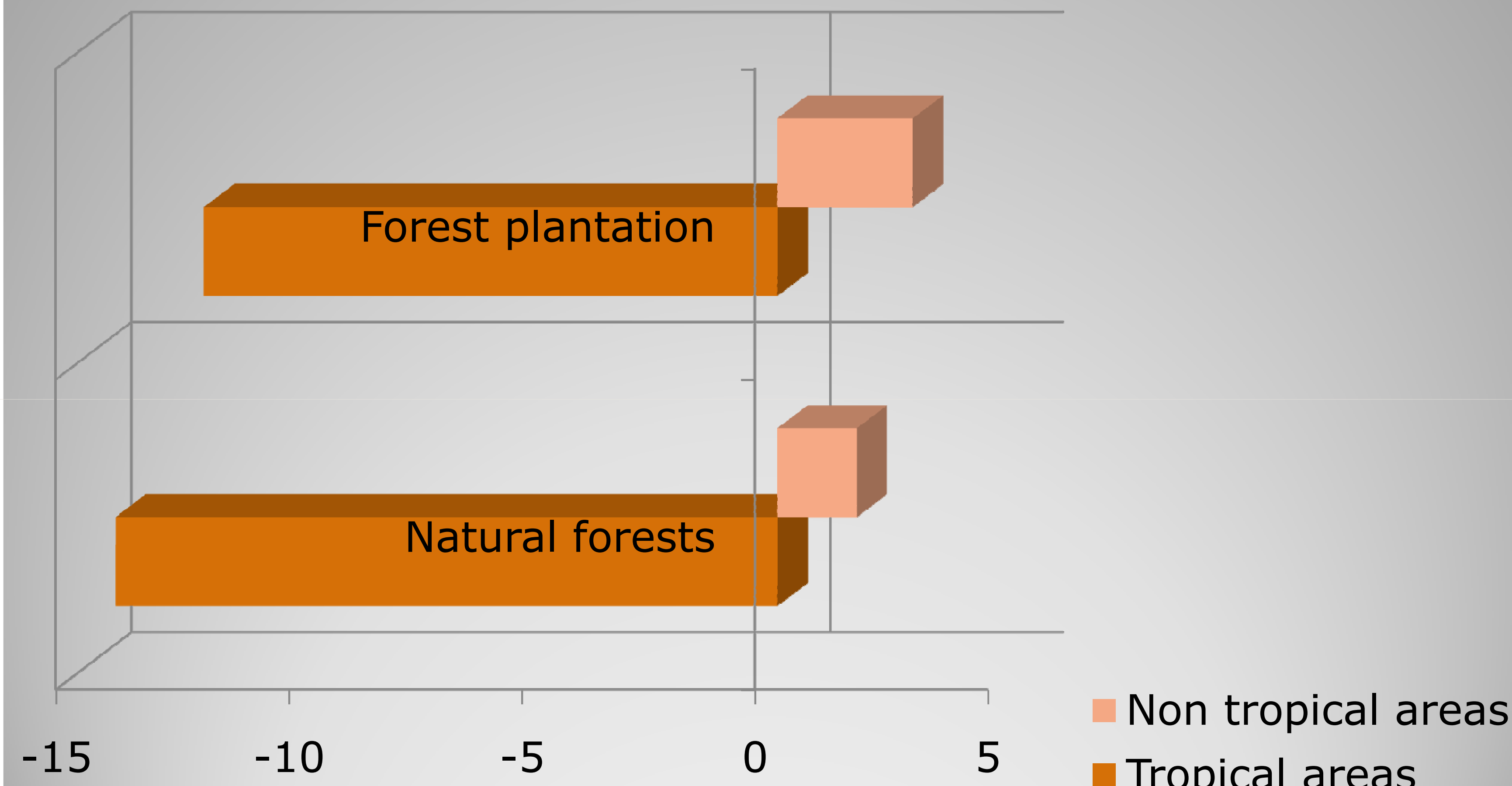
- Main reason = disjunction between costs and benefits for both forest exploitation and forest conservation.



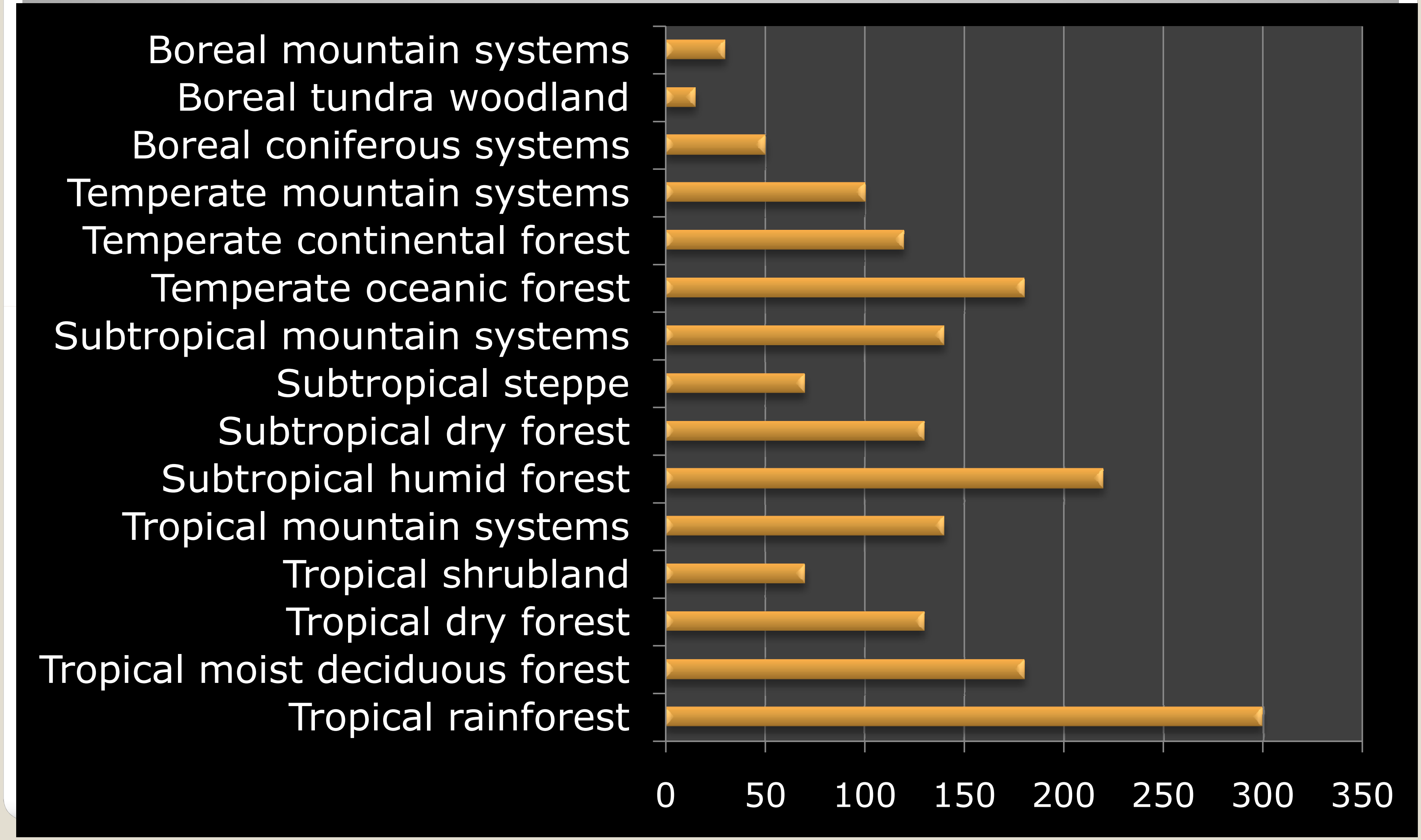
Greenhouse gas emissions from regions of the world

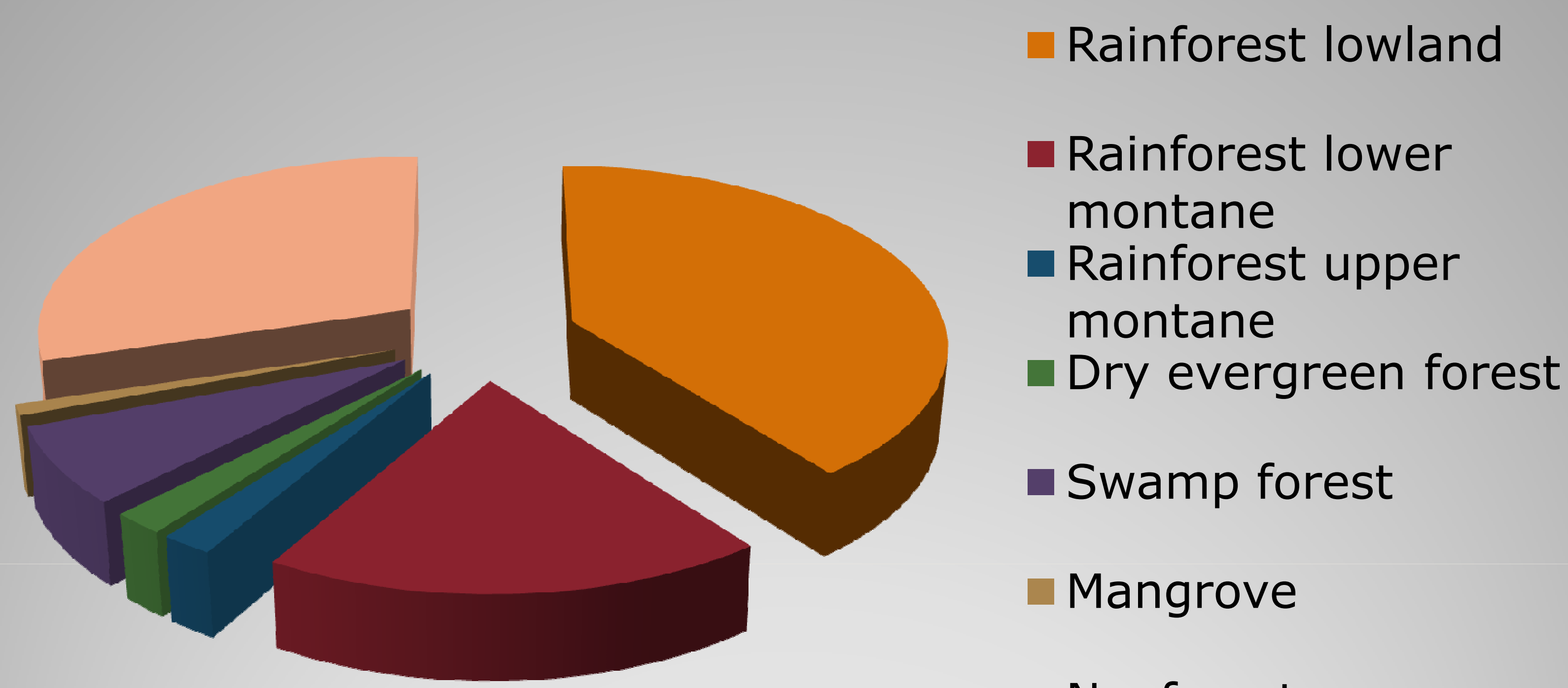
Sharma et al. (2006)

Annual net change in global forest cover from 1990 – 2000 (million ha) (FAO, 2001).

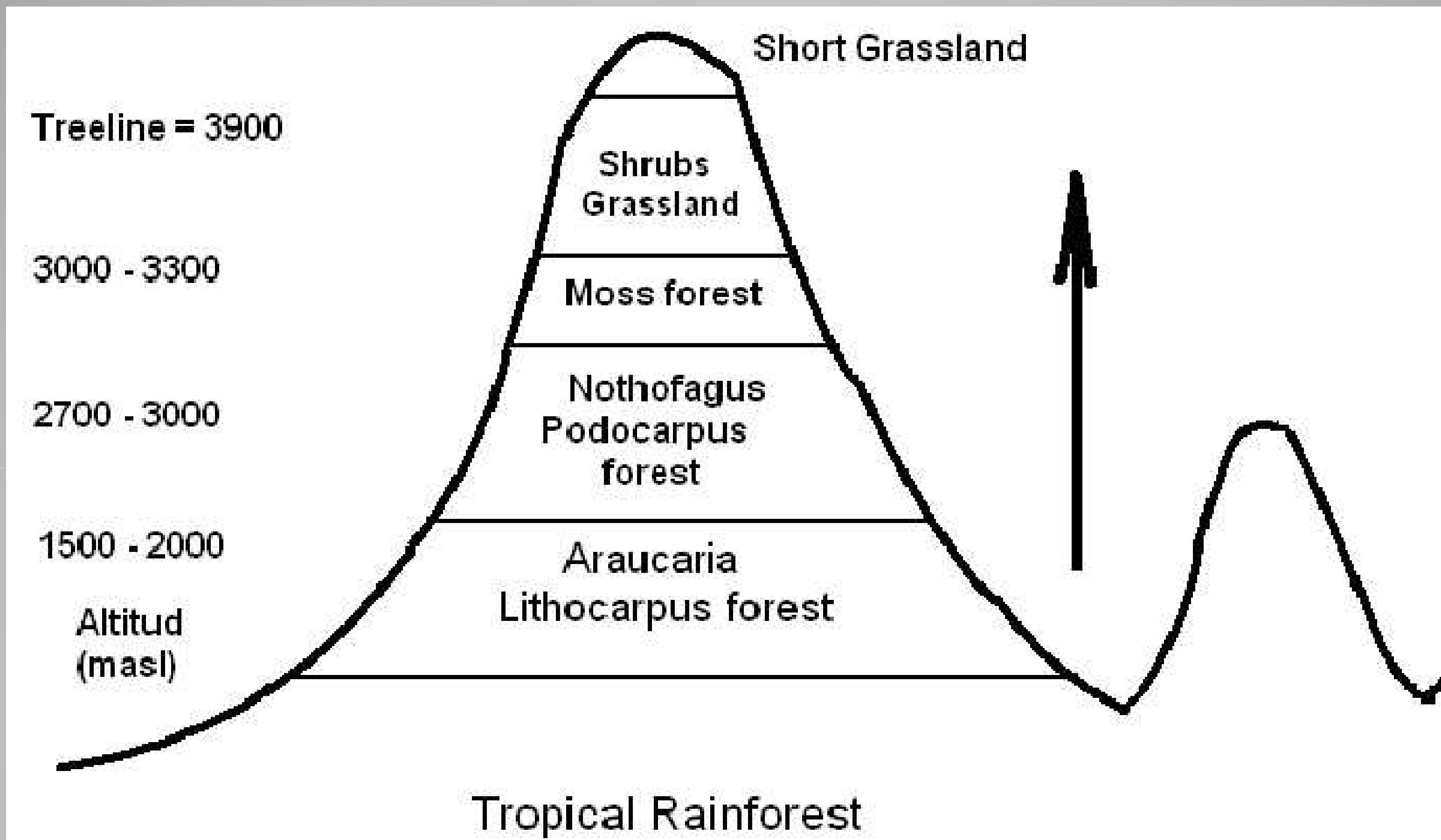


Estimated Above-ground biomass in natural forests (t/ha).
(IPCC, 2006)





PNG land cover types (%) (UPNG, 2002)



Short Grassland
Treeline = 3900
Shrubs
Grassland
3000 - 3300
Moss forest
2700 - 3000
Nothofagus
Podocarpus
forest
1500 - 2000
Araucaria
Lithocarpus forest
Altitud
(masl)
Tropical Rainforest

Forests as sinks

- Tropical forests: greatest potential to sequester C through reforestation, agro forestry and conservation. 2/3 of total terrestrial C in forests (standing & under-storey biomass, leaf, debris, soil).(Upadhyay et al. 2005). About 3/4 of PNG (460, 000 km^2) is under primary forest (McAlpine and Quigley, 1995).

- They sequester 20-100 times more C/ha than croplands (Brown & Pearce, 1994). CO_2 sequestration by forests is more cost-effective. (Schlamadinger *et al.* 2007). especially in lands with low opportunity costs.

- Positive results: Managed areas clearly distinguishable from surroundings that are not, natural regeneration appears, biomass denser:
- Net emitter of carbon ⇨ Sink (1-5 t/ha/year). If cutting for fuel wood > forest regeneration rate ⇨ Net carbon source.

Kyoto Implications

- Instrument available to pay those who provide the eco-service valuing carbon ⇨ first step towards broader economic arrangement in which other eco-services will be rewarded.

- Project concreteness & measurability checked independently by third-party accredited by Clean Development Mechanism (CDM) executive board. Stages: validation and verification to enable project registration, and Certified Emissions Reductions issuance

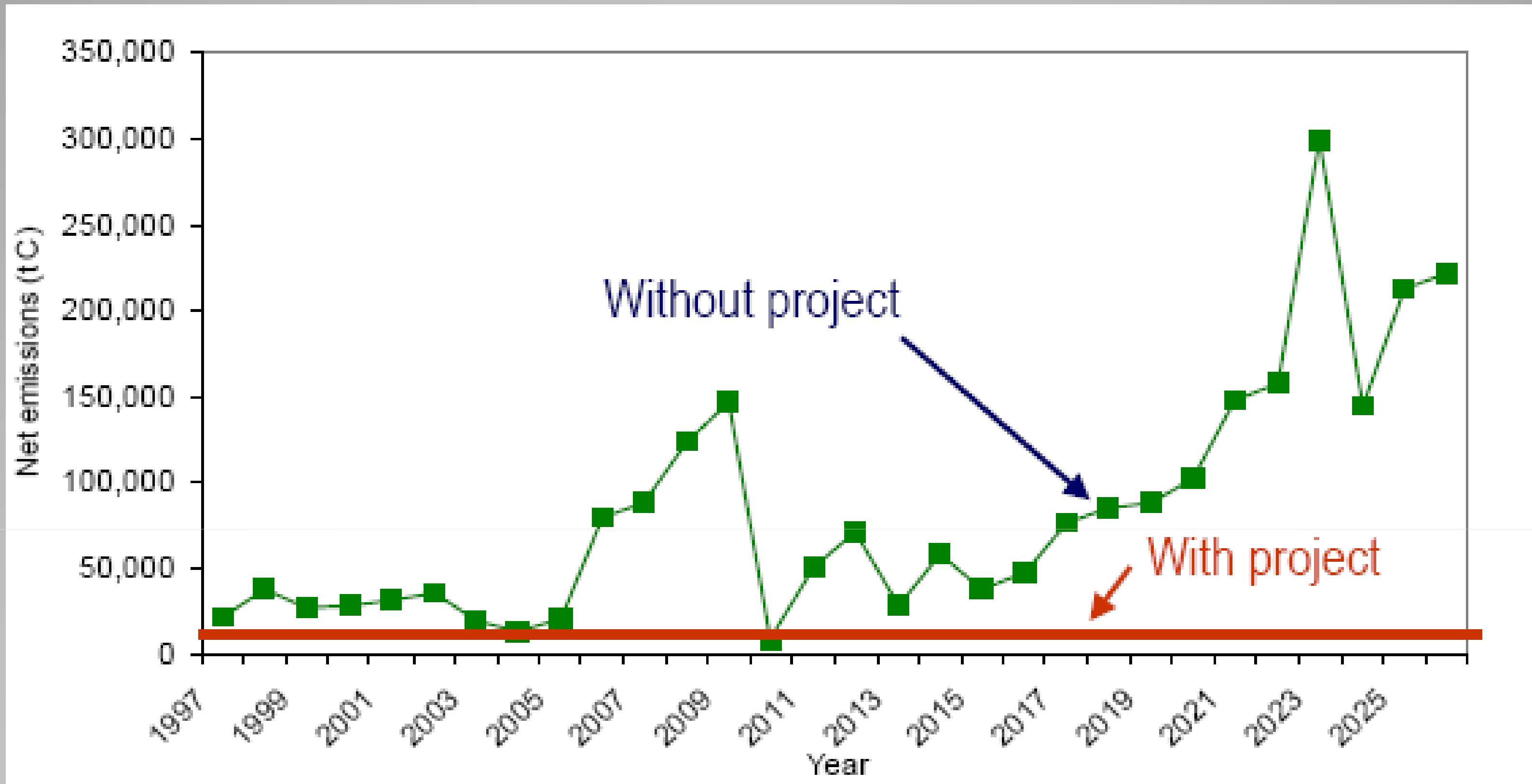
  (One carbon credit = one metric ton of CO_2 emitted)

- However, Kyoto Protocol only recognizes forests as C sinks (Aff & Ref.) NOT as C sources (avoiding def.) ⇨ fails to avoid further emissions from def. ⇨ open option to reduce deforestation rates by CFM (14% of forests in developing countries).

AR CDM *vs.* REDD

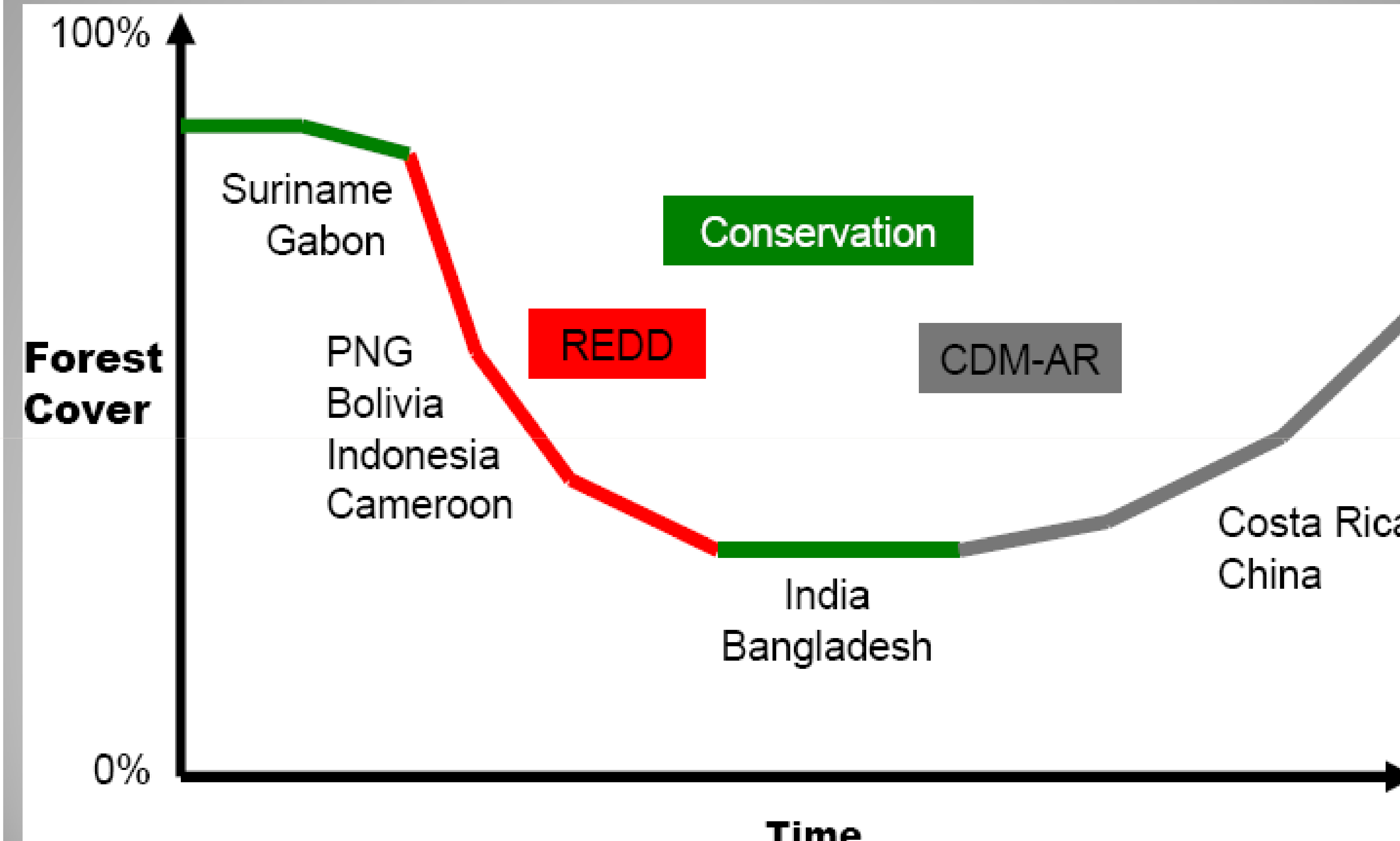
- CDM is restricted to aforestation and reforestation (AR CDM) for period 2008–2012. Aforestation = planting trees on land that has not been forest for at least 50 years. Reafforestation = planting trees on land that was not forest on December 31, 1989. Excludes management of native forests / reduction of emissions by avoiding deforestation. NO LONG TERM IMPACT ON GREENHOUSE EFFECT (photosynthesis in balance with respiration and decay in mature forests).

- United Nations Framework Convention on Climate Change (UNFCCC) in Dec 2005 initiated consideration of policy for 'reduced emissions from deforestation and degradation' (REDD). Countries that elect (after 2012) to reduce national level deforestation to below 1980–1990 level (baseline?) would receive post-facto compensation. Baselines at national level should detect and account gains **and** losses, by continuous inventories. Reward: only absolute gains. A project that can, through periodic measurements, demonstrate that its growth rates are above the regional baseline can claim that difference as a C credit produced by project action.



Typical baseline for a conservation carbon emissions offset project
(Dushku & Brown, 2003).

Strategic trends



PNG EFF Strengths on REDD

- Participatory proc., fair, transparent distribution of benefits.
- Financing scheme consistent with PNG Laws.
- Focus on peat swamp forests & secondary forests (?)

PNG EFF Un consistencies

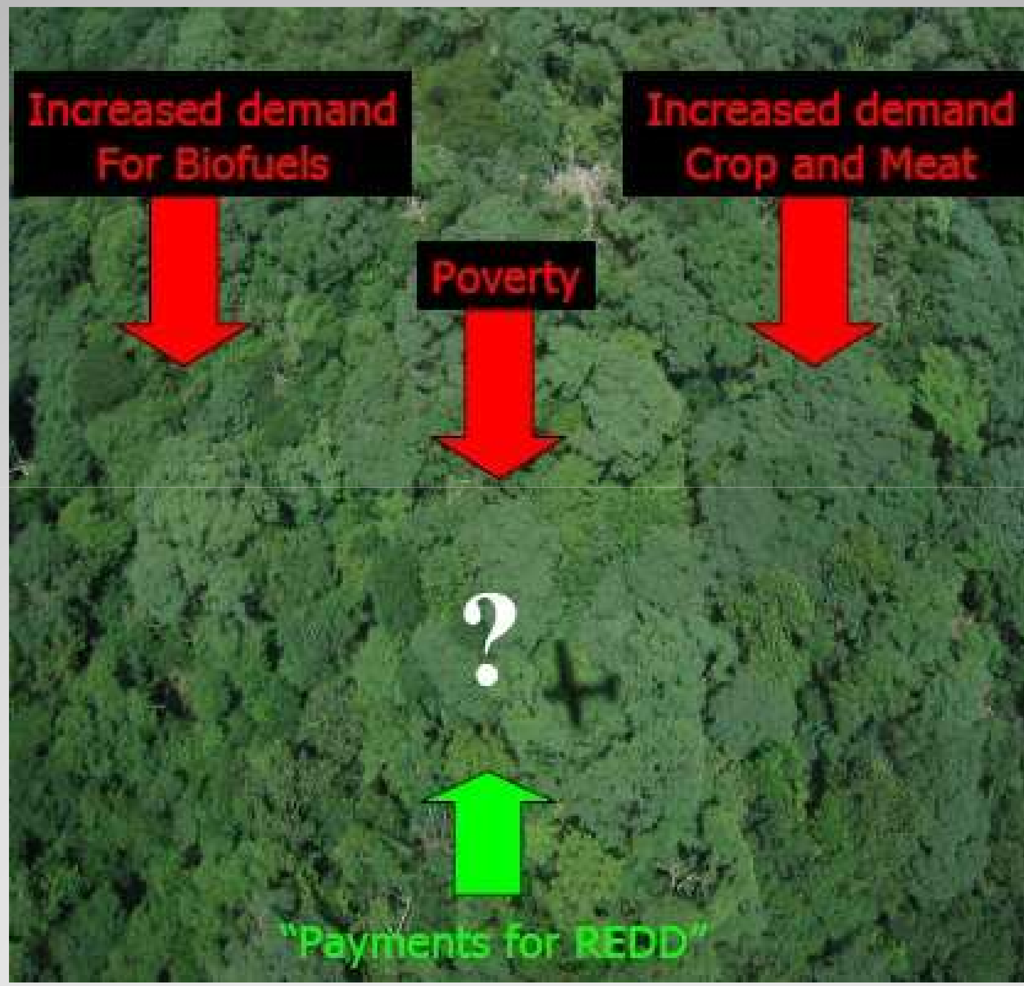
- Land registration must not be a precondition.
- All current & proposed industrial logging rights should be cancelled before the introduction of any carbon financing scheme in PNG.

Why CFM is not recognized under the Kyoto Protocol?

- Leakage = endogenous increase in carbon emissions as a result of emissions reduction elsewhere.
- Additionality: holding everything else constant, would a project have happened in the absence of the offset crediting system?
- Yes → project not additional. No → Project additional.
- Transaction costs likely high.
- Inability to demonstrate that without project implementation C would be emitted (need of 'without project' baselines).
- Small scale of CFM projects.
- By permitting avoided deforestation a market glut of carbon credits appears (excess supply of carbon)

  ⇨ price down ⇨ CDM counterproductive (Trexler 2003).

Can PNG reduce deforestation with REDD?

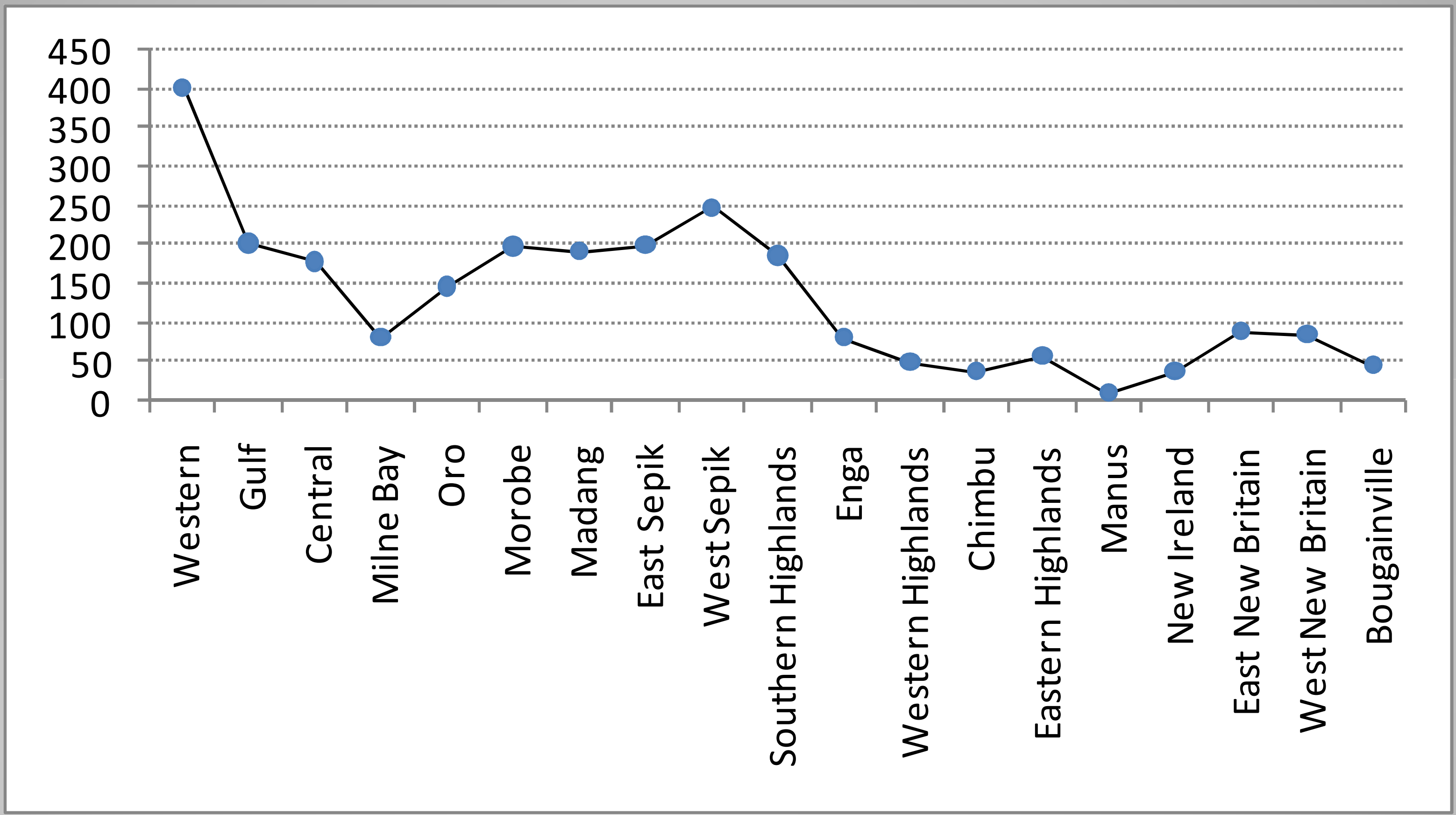


Questions

- Should a mechanism be based on avoided deforestation, or deforestation and degradation ?
- Should AR be dealt with only under existing CDM rules, or should the option to use “full forest estate” accounting be explored ?
- How closely should carbon stocks be tracked ?
- Rates of degradation in unmanaged forests ?
- Sorts of management activities under CFM schemes and how much carbon is saved as a result? Forest Improvement Technology – FIT suitable ? (follows natural regeneration, yields: 15 to 20 m^3/ha/year).

- How could the carbon stock changes be measured and monitored in a cost effective manner ?
- What would be the possibility of bundling several environmental services to reduce transaction costs?
- Will such payments benefit the “unrepresented” ?
- Rules/procedures for internal payment ?
- Kyoto and non-Kyoto markets possible ?
- Is there leakage to other areas? How much?
- Opportunity cost of this management ?

Criteria for Selecting Research Sites



Area (x10,000ha) of non-degraded rainforest per province. (UPNG, 2002).

- Local/regional interest + willingness to partner in project.
- Large enough to allow landscape inferences (such as watershed impacts); fits within the technical constraints of GEOMOD for data analysis.
- Adequate existing data sets on physical, social and economic conditions.
- Land cover maps derived from remote sensing imagery enabling construction of past land cover history extending back 10-20 years.
- Contains large tracts of intact forest + already developed areas.
- Risk of further forest fragmentation, but regional conservation focus.
- Reality-checking.

A Methodology

1) Identifying and stratifying the forest area

- Dominant tree species.
- Stocking density of trees.
- Age of tree.
- Aspect and position of hill slopes. A stand on the south aspect would have greater productivity than one on the north aspect.

2) Boundary mapping

3) Pilot survey for variance estimation and sample plot size

- At least 15 random circular plots for each forest type stratum of 5m radius. Measure the circumference at breast height (1.3m) of all trees above 4 cm. Consider trees on border if > 50% basal area fall within the circle. Or 20x10m (0.02ha) plots.

4) Calculating Optimal Sampling Intensity

$$n = CV^2 t^2 / E^2$$

where

- CV = Coefficient of variation of basal area
- t = student's t-distrib. n-1 degree of freedom, 10% prob.
- E = Sampling error at 10%

- **Permanent plot layout**
- Locating sample plots in field with a GPS.
- Slope correction in areas above 10°. Correction factor: LS= L/cos S, LS = corrected plot radius, S = slope angle in degrees, cos S = cosine decimal, L = plot radius.

- **Permanent plot measurements** (over a period of 5–10 years)

  CARBON POOLS: above & below ground biomass, soil organic carbon. Each carbon pool can have a different S^2 (MacDicken, 1997).

- **Biomass estimation of trees and saplings**

  Half of net change in biomass = C Seq. t/ha.

  (Δ Yr = Yr2 - Yr1)
- To convert C to CO_2: C x 44/12 (ratio of the molecular weight of carbon dioxide to carbon).

- **Biomass estimation of other plant forms and litter**

- Place randomly subplots of $1m^2$ in each 100 m^2 plots. Harvest above and below ground parts, place them in marked bags, weight and oven-dry to constant weight.

- Express biomass separately for aboveground and below ground components in t/ha.

- Collect forest floor material from ten 0.5x0.5m quadrants placed randomly in each stratum. Harvest all herbaceous live and dead shoots at ground level. Categorize material on the forest floor into

  (a) fresh leaf litter

  (b) partially decomposed litter

  (c) wood (including seeds) litter

  (d) miscellaneous litter.

- Calculate oven dry weight in t/ha.

- Moisture content (M_l) of oven dried leaf samples (W_{ld}):

$$M_l = (W_{lf} - W_{ld}) / W_{ld}$$

W_{lf} = fresh weight (g)

[50% of forest dry biomass = C]

- **Below Ground Biomass**

root: shoot ratio = 0.10 or 0.15 (tropical forests, in Nepal = 0.125).

- **Soil Carbon Estimation**

Dug 5-7 pits of up to 150 cm depth in different forest types. Collect soil samples from each pit at 0-10, 10-30, 30-60, 60-90, and 90-150 cm). Calculate soil bulk density for each soil depth.

Tree biomass allometries (relationship between the rate of growth of one body-part with another part or the whole body)

by harvesting trees, determining their dry biomass (W), and relating that biomass to their cylindrical bole diameter (D):

$w = a \cdot D^b$ (1) (Satoo, 1982)

$w = a + bD^2$ (2)

- Best predictors of *Above Ground Biomass of a tree (*decreasing order of importance): trunk diameter, wood specific gravity, total height, and forest type (dry, moist, or wet) (Chavez *et a*l, 2005)

Old growth lowland rain forest, La Selva (Costa Rica). Ladders are required to measure trees. Growth forms of lianas and other non-tree woody life forms necessitate specially designed traps for estimating biomass.

Non destructive method for determination of above-ground biomass over large areas

- Identification of random tree samples within the area, above-ground biomass for each sample: by allometric relations. Ex:
- TAGB = 1459.4 (a) – 28.903 (3) where
  TAGB = total above-ground biomass at pixel-of-interest in (kg/m^2),
  a = NDVI image.
- Selection of vegetation index:

NDVI	(NIR -RED)/(NIR + RED)
TNDVI	SQRT((NIR-RED/NIR+RED)+0.5)
SR	(NIR)/(RED)
MIR	(MIR-R)/(MIR+R)
VI	NIR-RED

- Examine relationship of the four vegetation index with corresponding TAGB with linear regression approach.
- **Derive TAGB for entire image with best model.**

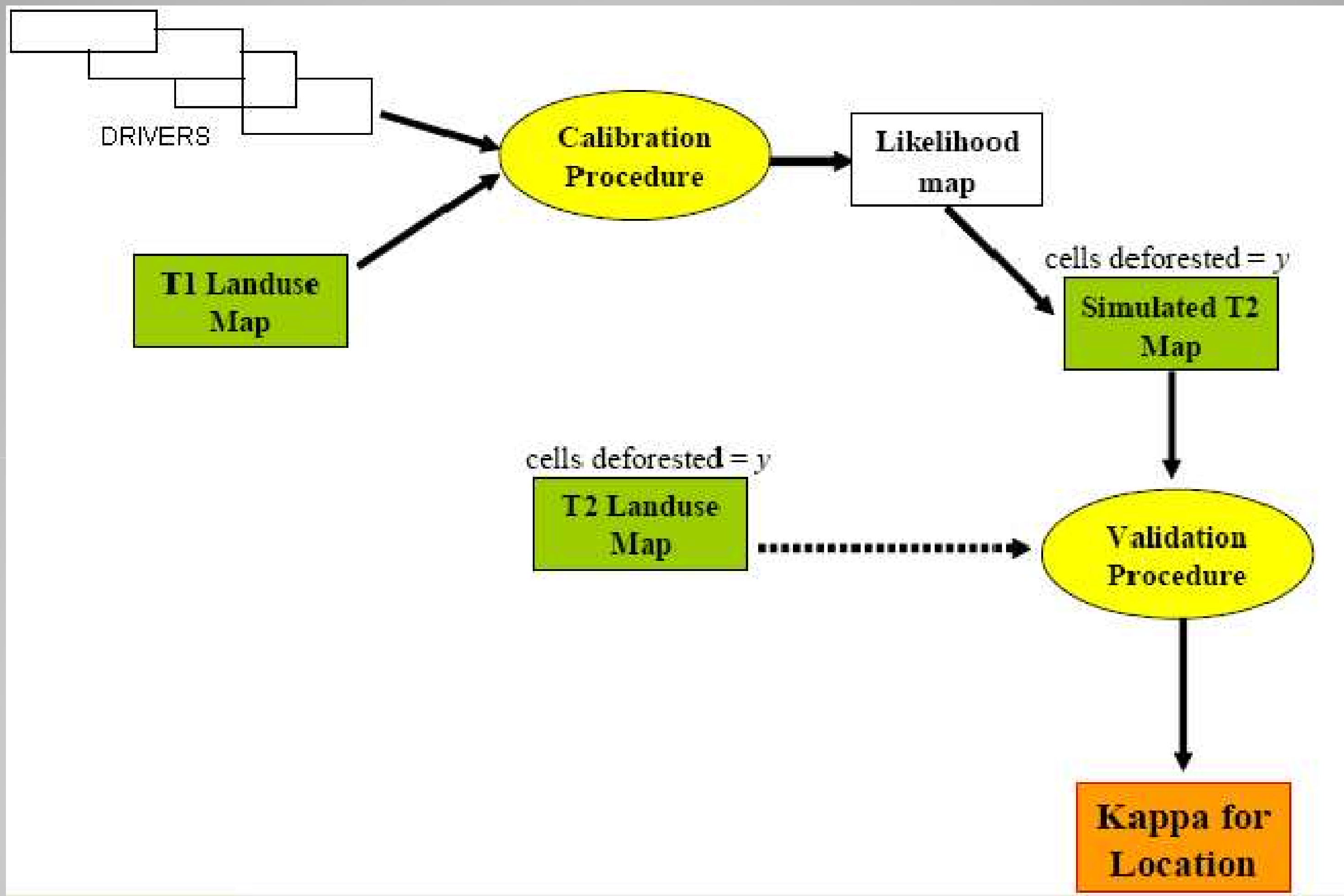
GEOMOD

- Build future carbon emissions based on how physical, cultural, and economic factors (each with assigned statistical weight) associated with past deforestation may drive further deforestation within the project area (Pontius *et al*, 2001). Predicts the **location** of land use change (of any kind detectable by RS) between two land categories forwards or backwards in time. Effective to see where forests are at risk of fragmentation/ conversion and plan strategic mitigation of negative trends.

- DATA NEEDED: Map of a beginning time and information concerning the number of grid cells of each category (how much trees actually have grown in different soil, sun and moisture condition) at ending time. GEOMOD selects the location of grid cells to classify as one of the two categories for the ending time. The change observed in any given landscape 'cell' is analyzed against a number of candidate drivers (distance from roads, slopes, population). Driver maps used for each calibration run are added → potential land-use change map.

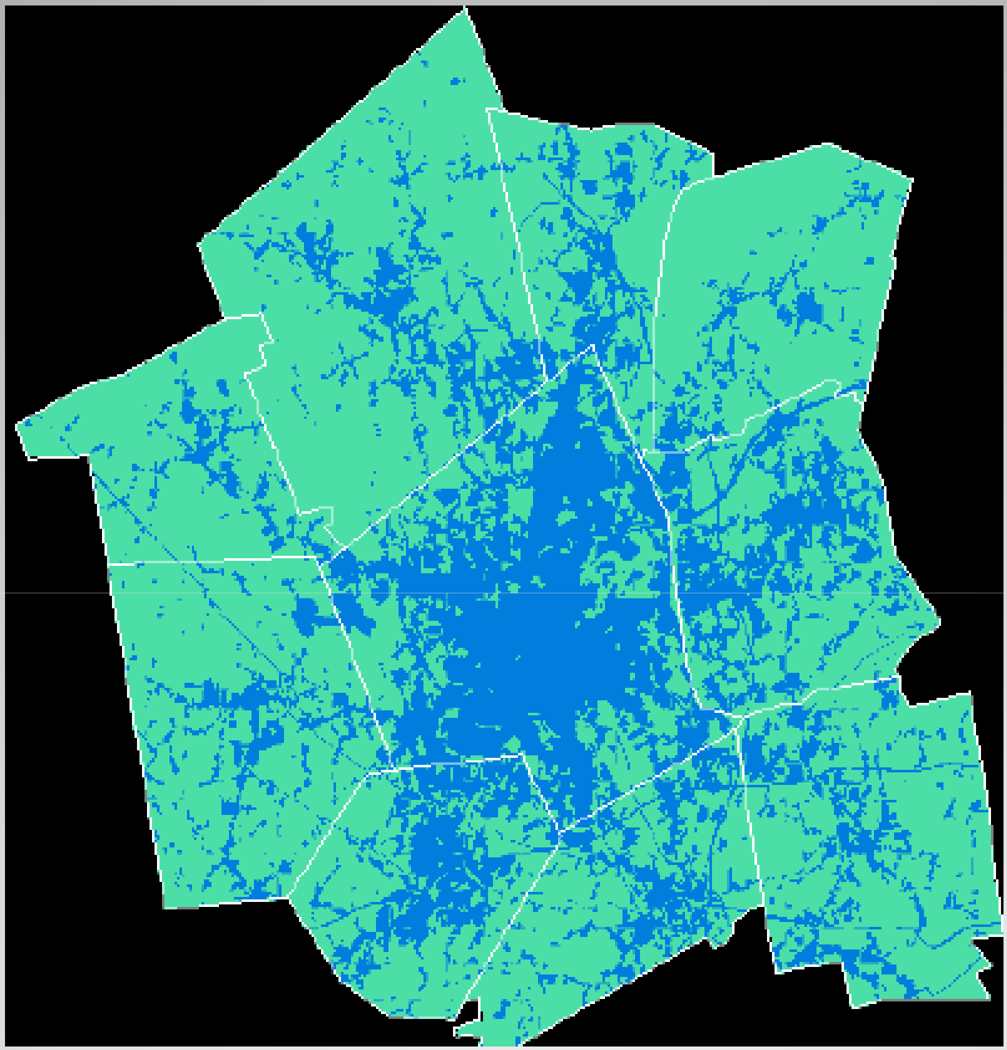
- The map of likelihoods (ranked potentials) is used to simulate deforestation at a third point in time, results are validated against the actual map of that same time period to test how well the drivers did in predicting the spatial pattern of deforestation. The closer the second time period is matched (as close to reality as possible): more confidence that those are the important factors that will affect the future distribution of development in a region. [Kappa-for-location (Klocation) statistic tells how much better than chance alone the model is in predicting areas that will be converted from forest to non-forest (with "0" = no better than chance alone and "1" = perfect predictor].
- Output = map of simulated landscape of developed versus non-developed cells at the ending time.
- Model requires a circular (iterative) process of calibration (with empirical data—measured and recorded—) and validation (with data held in reserve to see if the model is predicting correctly).

Search for the best agreement..



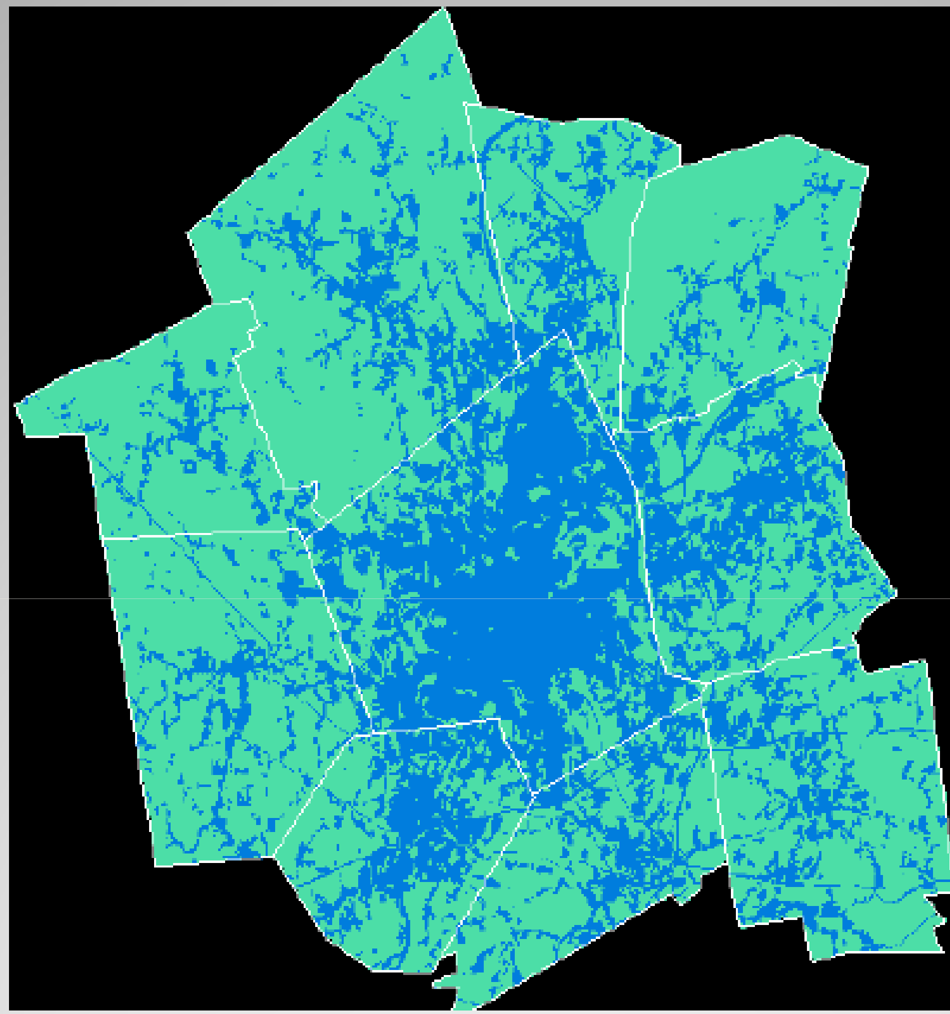
Validation Statistics for Connecticut Spatial Drivers
Time 1 = 1990, Time 2 = 2002 (Tyrrell *et al*, 2004)

Rank	Factor	Kappa for Location
1	Distance from 1985 Agricultural Lands	0.8928
2	Soil type	0.8881
3	Distance from 1985 Urban Areas	0.8859
3	Population Over Age 65 (1990)	0.8859
4	Density of Housing Units (1990)	0.8858
5	Population Density (1990 Census)	0.8855
5	Distance to Secondary Roads	0.8855
6	Owner Occupied Housing Units (1990)	0.885
7	Population Under Age 18 (1990)	0.8849
7	Distance to Railroads	0.8849
8	Elevation	0.8846
9	Distance to Major Rivers	0.8843
10	Distance to Local Roads	0.884

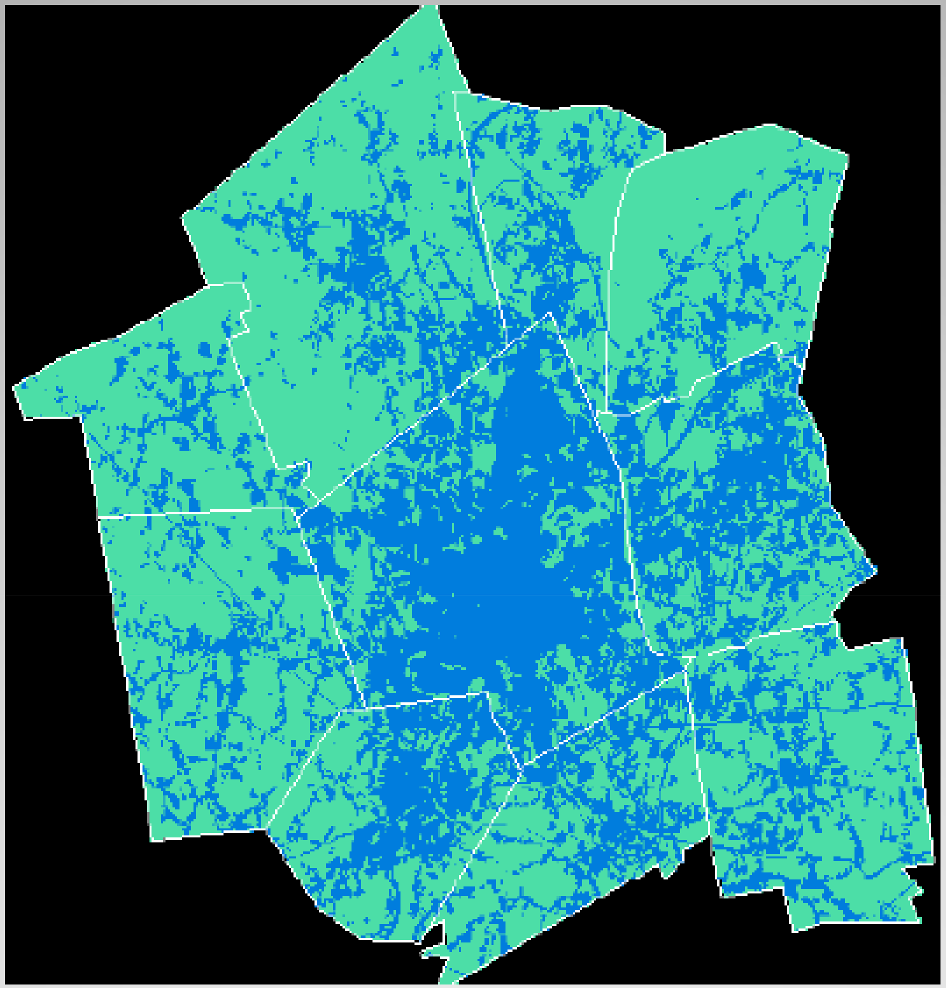


1. Image of developed versus non-developed of 1971

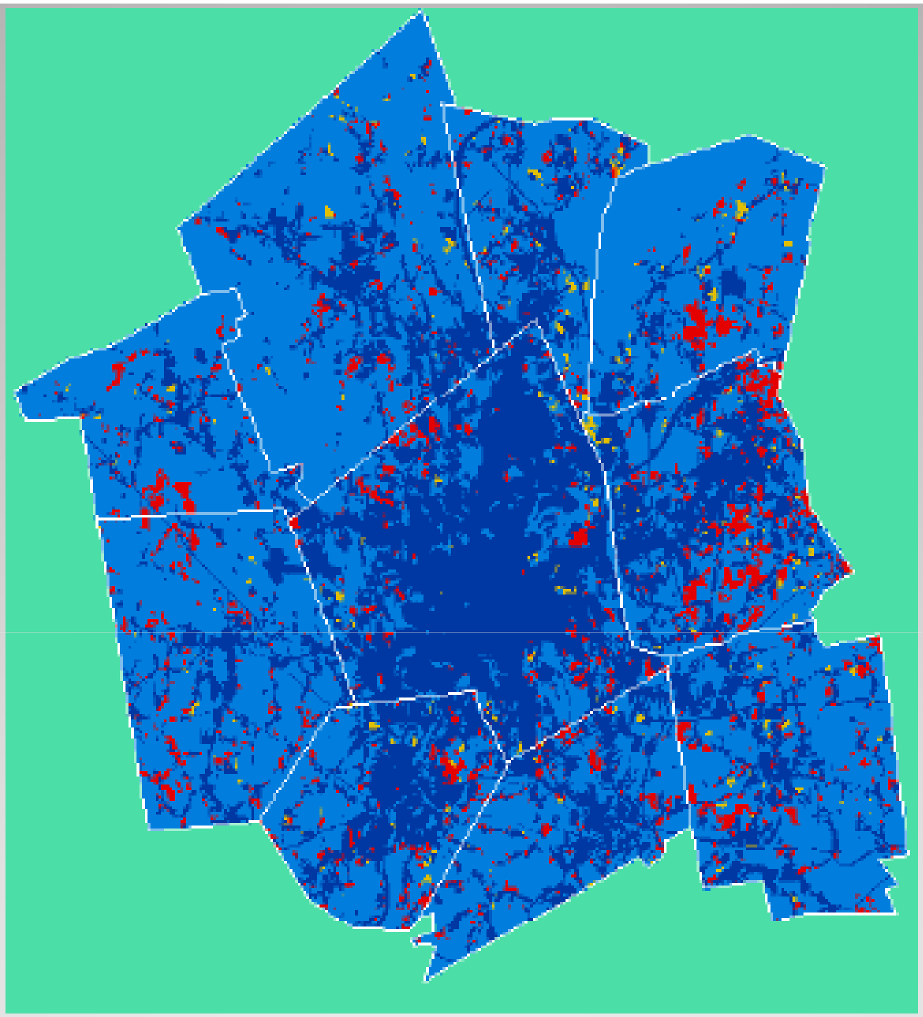
(Pontius & Chen, 2006).



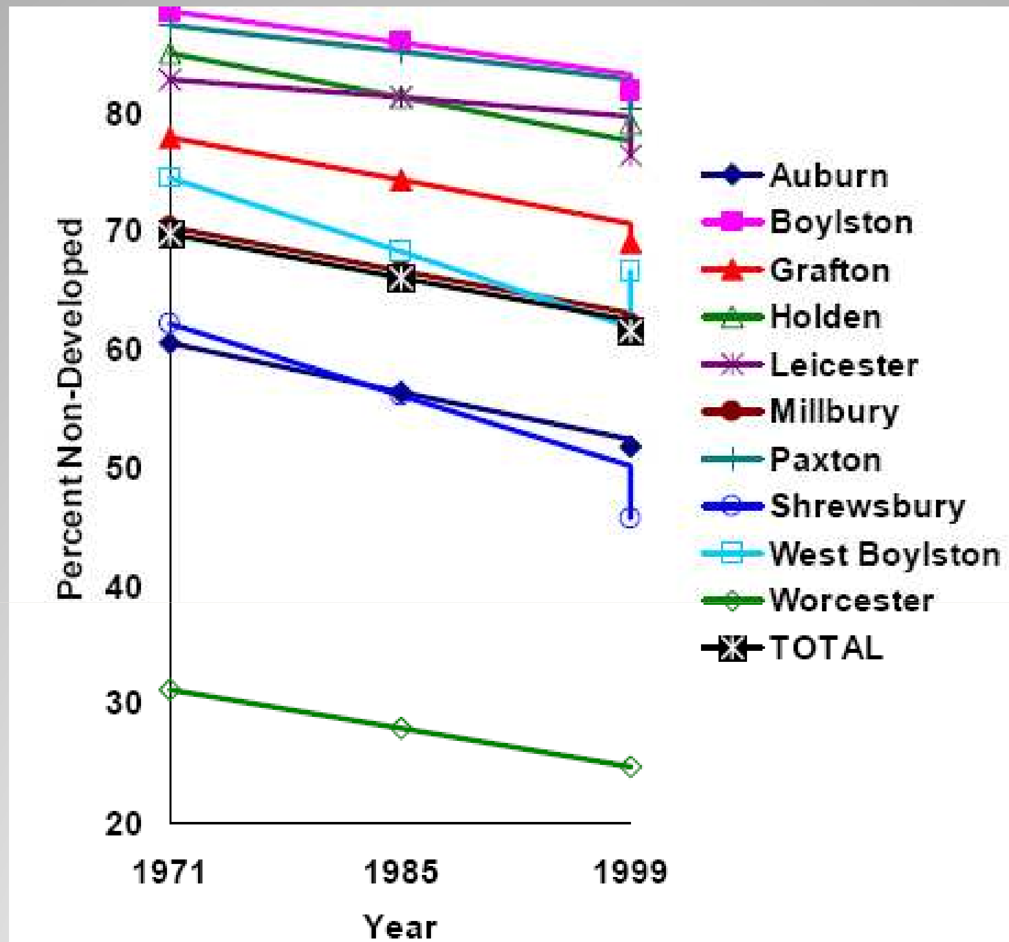
2. Beginning time image of developed Vs non-developed of 1985.



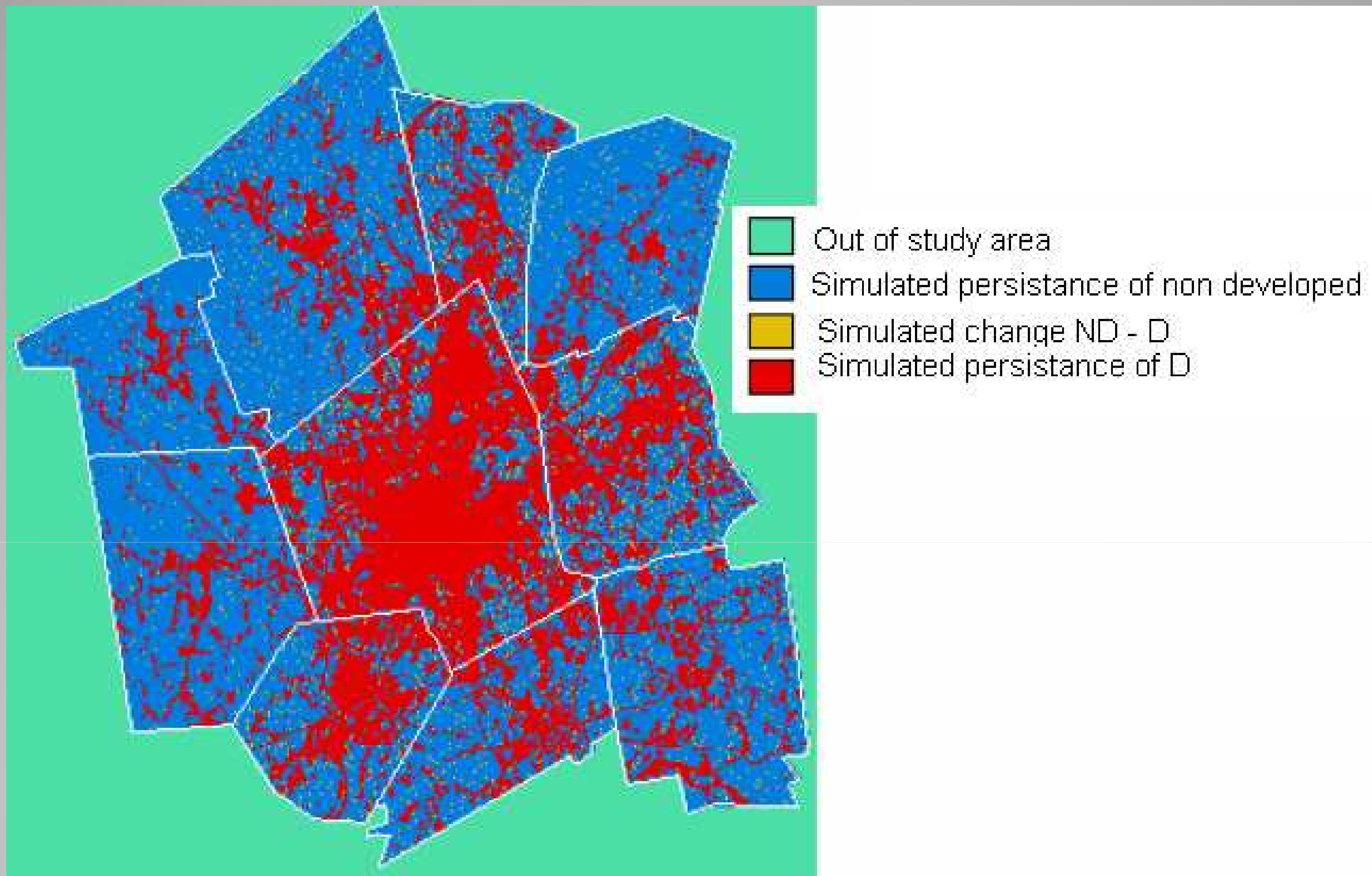
3. Validation image of developed Vs non-developed of 1999.



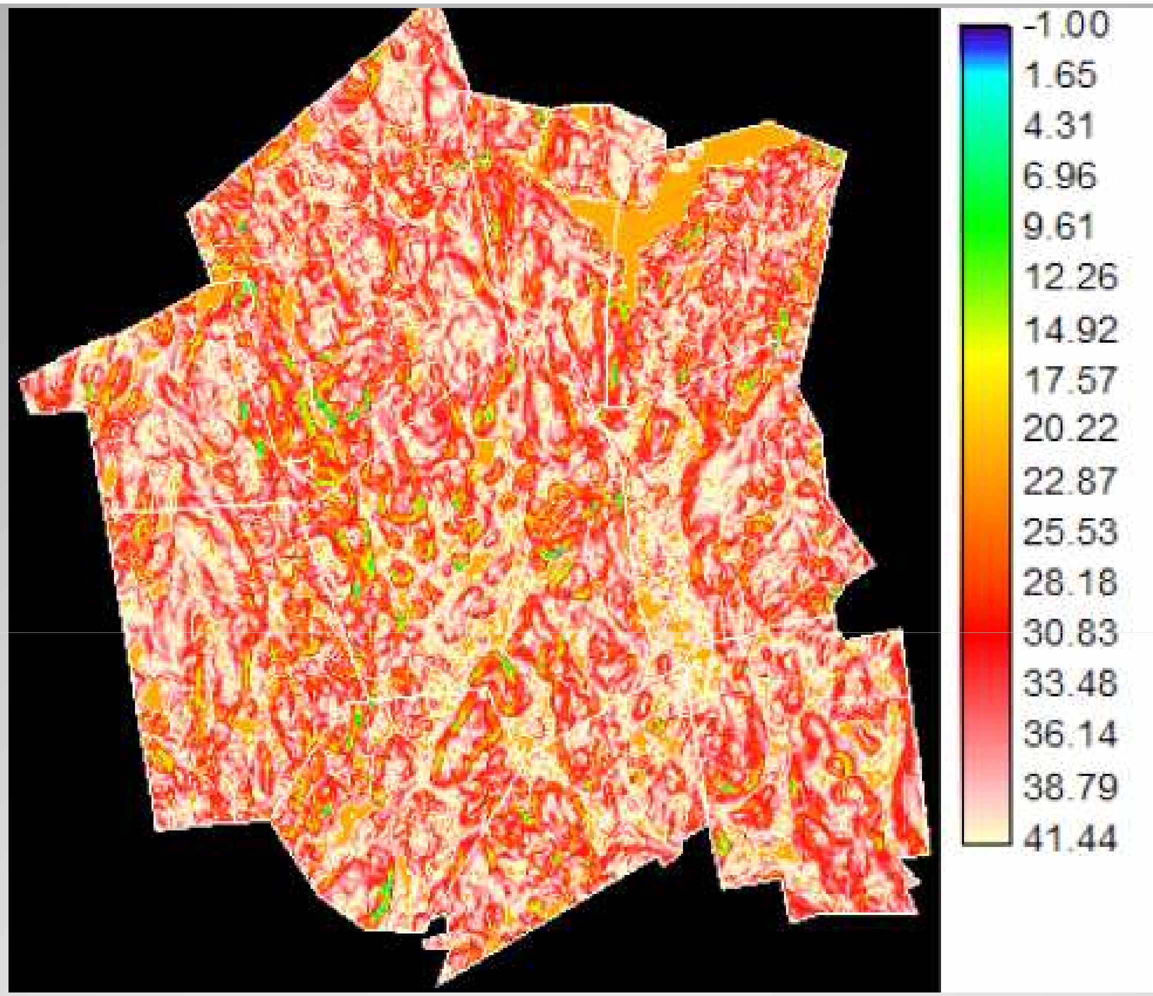
4. Crosstabulation of 3&4. Image of land change between 1985 and 1999. Classes: ND, ND-D, D-ND, D.



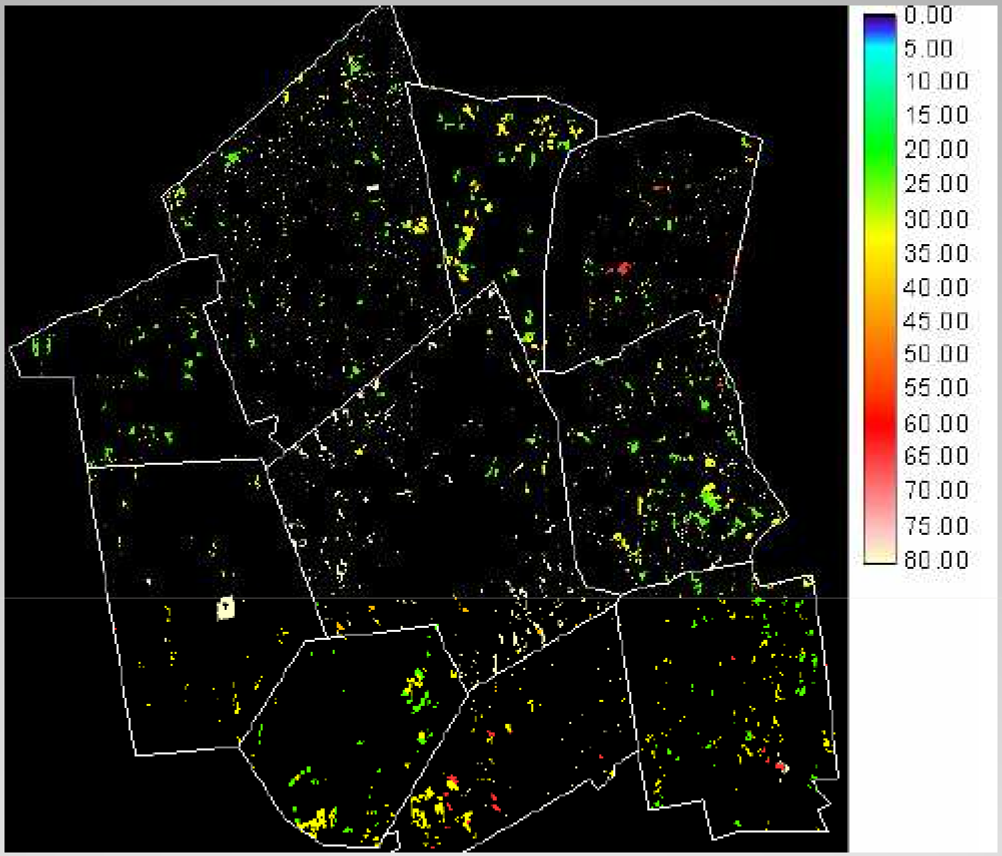
5. Percent non-developed for the 10 towns of the study area. The line interpolates the points of 1971 and 1985, then extrapolates to 1999, where it predicts with some error.



6. Predicted new development 1985-1999 image. Within each stratum a one-way of change is simulated (Stratum map must be specified). Quantity of non developed area specified in 5 is distributed among 10 districts.



7. Suitability map created from the slope map and the 1985 beginning time image.



8. Environmental impact image of decrease in C /pixel as a result of simulated development during 1985-1999.

Environmental impact of any particular simulation run

Impact(i) = Resource(i) x Ratio(i) x Ratio2(i)

- GEOMOD can analyze Env. Impact of any particular simulation run.

- **Impact(i) is the actual environmental impact in cell i**
- **Resource(i) is Biomass in each cell at beginning time**
- **Ratio1(i) is the ratio of potential impact (mass of C) / Env. Res. (mass of biomass) in cell I**
- **Ratio2(i) is the ratio of actual Env. impact/potential in cell i. If development method is by burning, ratio is higher than by biomass cutting.**

- **Ratio 1, Ratio 2 $\longrightarrow$ image / constant [0,1]**

CO_2fix model approach

- Quantifies full C stocks & fluxes of cohorts (group of trees/species with similar growth). Eg: (a) Pioneer/intermediate/climax groups, (b) species in a mixed forest, (c) understory/middle/upper layer in agroforestry system.

- Carbon stored in living biomass of cohort i:

$$Cb_{it+1} = Cb_{it} + Kc\,[Gb_{it} - Ms_{it} - T_{it} - H_{it} - Ml_{it}]$$

- Kc = constant to convert biomass to carbon content
- Gb_{it} = growth rate of stem volumes (from yield tables)
- Ms_{it} = Tree mortality due to senescence
- T_{it} = Branches, foliage, roots turnover
- H_{it} = Harvest
- Ml_{it} = Mortality due to logging

- In 2001: 800 users in 72 countries.

- To model stored C in multi-cohort stands, CO2FIX modifies the growth of each cohort due to tree interactions (tree growth in a cohort is influenced by presence of other trees).

- Model provides two basic options for modeling the interactions between and within the cohorts:

  a) Competition of a cohort as a function of total stand biomass,

  b) Interaction of the cohort in question as a function of biomass of each other cohort separately.

- Each decomposition compartment has specific decomposition rate.

- Growth rates for foliage, branches and roots are calculated from the growth of stem volumes with time-dependent allocation coefficients. Ways to define stem growth of each cohort:

  a) as function of tree or stand age (conventional yield tables),

  (b) as function of the cohort total and maximum aboveground biomass (BHT).

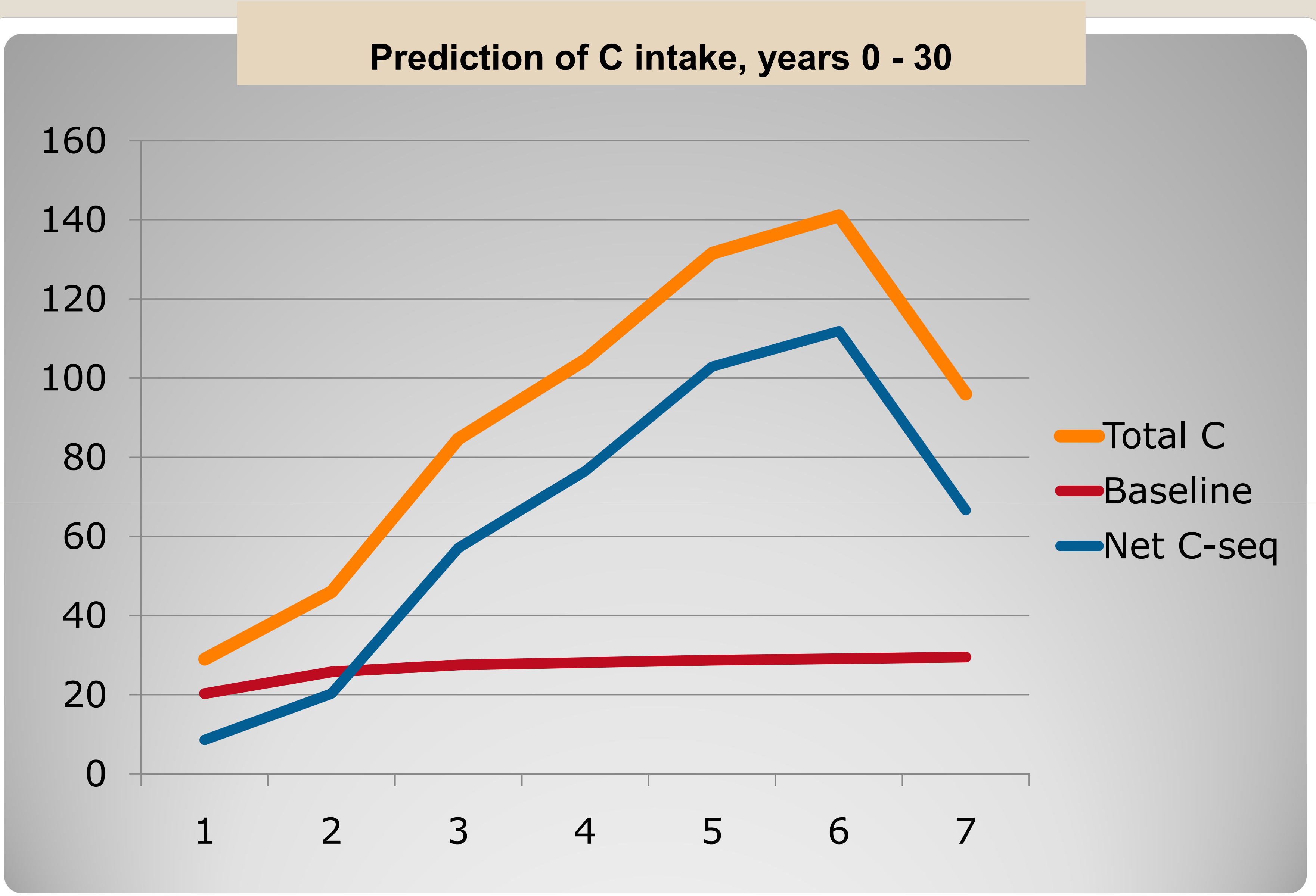
C pools (Mg C/ha) and sequestration in a Teak (*Tectona grandis*) plantation – 30 years (Iskandar *et al*, 2006)

Year	Living aboveground	Living belowground	Soil Carbon	Total C	Baseline	Net C-Seq	CO_2 Equiv.
0	0	0	29	29	20.3	8.6	31.6
5	12.3	5.2	28.6	46	25.8	20.3	74.3
10	30.5	11.2	43	84.6	27.5	57.1	209.4
15	32.7	10.4	61.5	104.6	28.1	76.5	280.6
20	52.6	14.1	64.9	131.5	28.7	102.9	377.2
25	56.1	13.2	71.7	141	29.1	111.9	414.4
30	0	0	96.1	96	29.5	66.6	244.3

Model assumption: plantation density of 400 trees ha-1, with 10% thinning at year 10 and clear fells at the age of 30 years.

Baseline = grassland without land use change. Basic input in biomass module: stem volume growth and allocation pattern to foliage, branches and roots.

Biomass growth estimated as function of stands age. User define areas of each land use (CO_2Fix files) that passes to a different one, and change rate of each transition.



Prediction of C intake, years 0 - 30
160
140
120
100
80
60
40
20
0
1
2
3
4
5
6
7
Total C
Baseline
Net C-seq

Economic benefits of CFM

- C sequestration rate for CFM in India and Nepal = 2.79 tC/ha/yr (10.23 tCO_2ha/yr) normal management conditions and after NTFP extraction. This is worth $162.84 ha/yr (rate of US$ 12 /t CO_2, biomass data from India), or US$ 34.45 ha/yr (at US$ 5/t CO_2 data from Nepal).
- Philippines: Increase of more than 1 t/ha = 2% growth/year of C (= 4 t CO_2 /ha/year).
- Tanzania's (34 million ha forestlands) benefit from REDD policy: $630 million/year, or $119/rural household (Zahabu *et al*, 2007).
- Global CDM market worth = US$ 50-60 billion/year (Ranganathan, 2007)

- Buyers of emission reduction units from sinks projects:

  Governments (central and local), the private sector (hydropower & electricity companies), international communities (BioCarbon Fund, World Bank - US$4 per ton CO_2). Commitment from Norway, UK, Australia. Development agencies / Banks ($40B/y), Bilateral donors ($80B/y), Kyoto market (low $B/y), Voluntary markets (lower $B/y), NGOs ($100sM /y).

- Sellers: the community

- Tommich *et al.* (2002) suggest a world price of $25 per Mg C to shift incentives from forest conversion (including logging) to conservation in Indonesia, while current CDM prices are only between $3 and 5/Mg C.

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