Socioeconomic determinants of landscapes and consequences for biodiversity and the provision of ecosystem goods and services

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OBJECTIVES : The AMAZ project aimed at identifying the socio-economic factors that determine the composition of diversified landscapes and ultimately influence the conservation of biodiversity and production of ecosystem goods and services. While legislation is limited in its ability to control deforestation, small farmers who continue to exploit one of the planet's richest natural resources remain poor and have limited access to public services and technical support. The AMAZ project addresses this double paradox by looking for mechanisms that would lead colonizers to utilize forests differently, ensuring sustainable development and conservation of the natural capital.

SITES : In two regions (Brazil and Colombia) we selected three landscape windows, each comprised of 3 groups of 17 contiguous farms. The regions represent different modes of rainforest colonization initiated at different times, 15 to 60 years ago (Table 1).

Tableau 1. Main characteristics of the landscape windows

Country	« Landscape Window »	Deforestation start	Average farm area (ha)	Forest (%)
BRAZIL	Palmarès II	1990	25	44
	Maçaranduba	1994	60	40
	Pacajá	1997	60	70
COLOMBIA	Traditional	1950	64	2
	Agrosilvopastoral	1940	20	2
	Agroforestry	1950	21	6

METHODOLOGY : A simple multidisciplinary model (figure 1) and a rigorous research protocol have allowed us to construct 6 tables that synthesize several thousand variables: 68 socioeconomic, 30 landscape units and 13 landscape metrics, 4105 taxonomic units from 7 different groups, 116 variables describing farm production and 53 that describe soils and their respective ecosystem services. (fig 1).

Socio Economic: 306 farms were analyzed with three different questionnaires related to individual trajectories (32 variables related to migration, education, professional and family status), economic situation (15 variables on income and access to credit) and production systems (21 variables). A socio-economical classification into 13 classes and 7 categories of production systems has been established.

Landscapes : Analyses provided a set of landscape metrics to describe the composition (% of different land uses) and structure (fragmentation, connectivity, diversity) of each window, with 30 land uses observed across the initial set of 306 farms Indicators of composition, structure and dynamics of landscapes were created (annex 1).

In 54 farms representative of socioeconomic and landscape conditions of the landscape windows, biodiversity and the provision of ecosystem services were measured at five points, equally spaced along the largest farm diagonal (270 points sampled in total).

Biodiversity : Communities of plants (3404 species identified in total), termites (29 genera), ants (54 genera), earthworms (21 sp.) and soil macroinvertebrates (18 orders), birds (338 sp.), Saturnidae (75) and Sphingidae (61) moths, and Drosoplilidae (100 sp.) were recorded. Thirty new species have been discovered. For example, 20 of the 21 species of earthworms were new to science. Three composite indicators of species richness, diversity and « naturalness » have been generated.

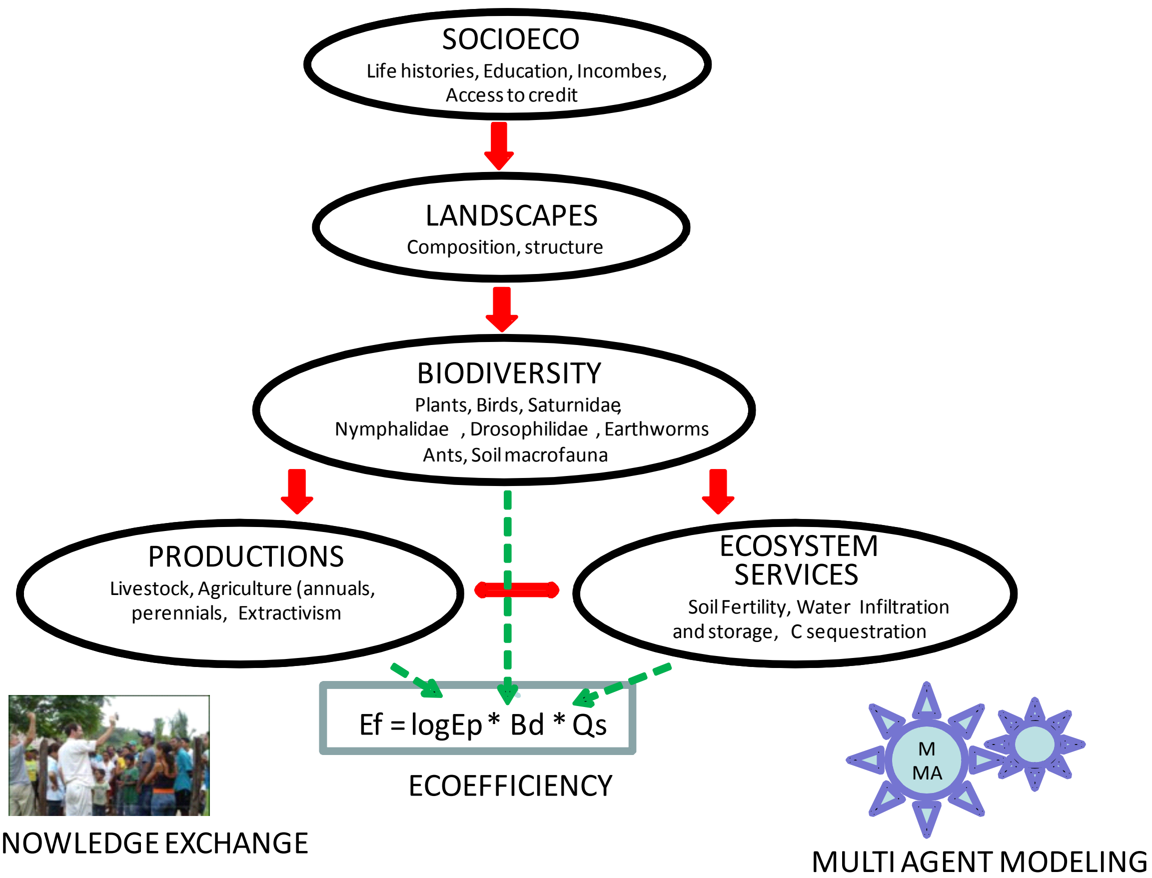


Figure 1 : AMAZconceptual model*. Red arrows represent the cascading effect of socioeconomic environment on landscapes, biodiversity, agricultural productivity and ecosystem services. Exchange of knowledge and multi agent modeling allow for the scientific knowledge acquired to become operational. The eco-efficiency index combines production efficiency logEp (log revenues divided by the number of hectares uses and by UTE labor units), biodiversity (a composite index ranging from 0.1 to 1.0) and soil quality (a composite indicator ranging from 0.1 to 1.0 that summarizes soil ecosystem services).*

Productivity : Agricultural productivity (farming, livestock or forest extraction) were detailed in each farm, in gross amounts, caloric or protein equivalent as well as commercial values of each product.

Soil Ecosystem Services: Soil physical, chemical, morphological parameters, and C stocks were measured with a total set of 53 variables at each of the 270 sampling points. This allowed for measuring of hydraulic services (water infiltration and storage in soil, plant available water), C storage in woody biomass and soil (from 0 to 30 cm depth) as well as chemical fertility (indicators of soil quality according to Velasquez et al., 2007).

Co-variation : Co-variation among the six tables was assessed with indicators of vectorial correlations RV and Multiple Coinertia analysis and tested with permutation tests on table lines (Dolédec et Chessel 1994).

Eco-efficiency: An eco-effciency index was developed to measure the capacity of farms to generate income (the Ep term, measures incomes per ha and per unit of labor), while preserving biodiversity (composite index ranging from 0.1 to 1.0) and ecosystem services (index built with soil ecosystem services values, ranging from 0.1 to 1.0

RESULTS: After testing the general hypothesis of co-variation among data sets, we characterize 7 socio-economic farm types and evaluate and discuss the respective eco-efficiency of each type.

COVARIATIONS: significant co-variations were observed between all of the 6 types of data collected (table 2).

*Table 2: Matrix of RV matrix covariations among the six types of information. [permutation tests (n=999) significaant at *≤ 0.02, **≤ 0.002, ***≤0.001].*
DEMOF : family histories ; DEMOQ : quantitative sociological dat ; PROD-SYST :production systems ; LANDSCAPE : landscape metrics ; BIODIV : Biodiversity ; ECO_SERVICE : soil ecosystem services

	DEMOF	DEMOQ	PROD-SYST	LANDSCAPE	BIODIV
DEMOF					
DEMOQ	0.355***				
PROD-SYST	0.193*	0.232***			
LANDSCAPE	0.226**	0.370***	0.304***		
BIODIV	0.196*	0.423***	0.248***	0.364***	
ECO-SERVICE	0.214***	0.414***	0.269***	0.488***	0.606***

SOCIO ECONOMIC CONDITIONS AND PRODUCTION SYSTEMS: Production systems were classified into 7 types according to 5 variables that had best separated the farms in preliminary analyses: production type (9 categories) and size of farms (5), presence of hired manpower (5), outside farm incomes (3) and income per capita (4) (fig 2). These 7 systems are:

Types 1 - pioneer fronts (mainly in Brazil) with small-scale livestock production or annual cropping systems on farms of variable size;

Type 2 - production systems with farmers that benefit extensively from off-farm activities;

Type 3 - large-scale livestock production systems (in Colombia) run by the wealthiest landowners;

Type 4 - diversified small farmer systems (Brazil and Colombia) representing the lowest income group (comparable to farmers in of type 1);

Type 5 - dairy-based systems associate with a variety of products in Colombia (high incomes, large areas and contracted labor);

Type 6 – small- to medium-scale livestock production systems

Type 7 - intensive dairy production or perennials cropping systems managed by small, yet relatively wealthy farmers

INCOMES : Farms incomes increase exponentially from pioneer fronts (types 1 and 4 with diversified production systems) to large-scale intensive cattle ranching (type 3), in sites deforested long ago. Type 7, which comprises eco-intensified systems (agroforestry associated with livestock breeding in Colombia) is the only production system that generates acceptable incomes on small areas (fig 3 and annex 1).

LANDSCAPES : The wide array of management histories and time of colonization has created diverse landscapes. The composition, spatial organization and temporal dynamics of the 30 types of land use have been mapped and quantified, for points (100m circles centered on each of the 270 sampling points), the 54 sample farms, landscape sub windows (17 contiguous farms) and windows (annex 2). A composite indicator of landscape integrity (with values ranging from 0 to 40) measures the degree of conversion and connectivity in each landscape use.

BIODIVERSITY : Each of the three synthetic indicators (raw and rarefied specific richness, naturalness) shows degradation along the gradient of land use intensification ($p<0.01$) (figure 2c), with a highly significant effect of sites (fig. 5) and a very strong link with landscape indicators.

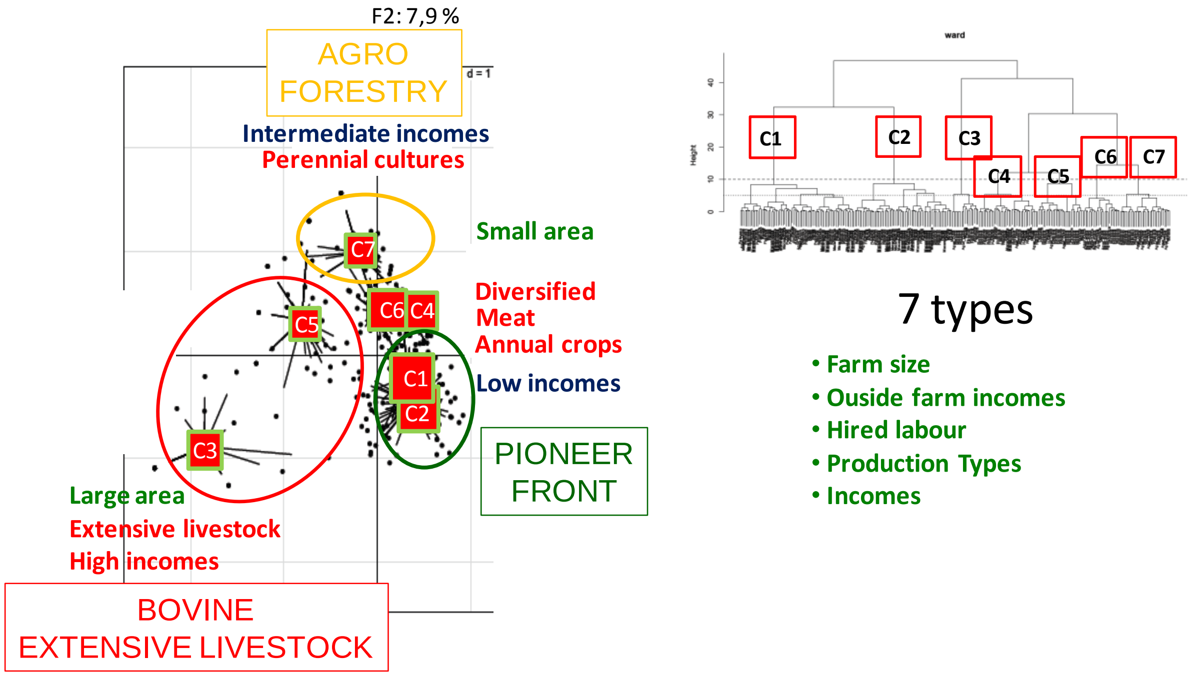


Figure 2 : Distribution of the 54 farms among the 7 production system types. *(a) projection of farms in the factorial plane of a Multiple Component Analysis: size of squares surrounding numbers is proportional to the landscape integrity indicator (see below); (b) eigenvalues of ACM; (c) classification in 7 types generated by hierarchical analysis.*

ECOSYSTEM SERVICES : Significant differences were observed among landscape windows and farms of the same socio-economic type. While chemical fertility and C stored below 10 cm in soils increase with intensification as a result of the initial burning and deep rooting of grasses, hydric services and C storage in surface soils and aboveground biomass are all reduced under more intense forms of management

KNOWLEDGE EXCHANGE: A close collaboration with local communities allows for the design of participatory indicators of services (ongoing project ; FR).

ECO-EFFICIENCY : An indicator of eco-efficiency is proposed :

$$\boxed{Ef = \log Ep * Qs * Bd}$$

With Ep, efficiency of production : incomes per ha used and per person working; Qs : soil quality (indicator GISQ* that varies from 0.1 to 1.0) ; Bd : biodiversity indicator built as GISQ on species richness data. Ef varies among production types (p=0.08) and within them. Ef was found to be highest (.75) under eco-intensified agroforestry systems (type 7), intermediate (0.43 – 0.48; respectively) in system types 4 and 6 (limited incomes), low in types 5 and 3 (0.35 and 0.38; respectively) where high incomes are associated with a high degradation of soils and biodiversity and minimum (0.32) in young pioneer fronts (T1) due to minimal income generation. The high variability observed in each type suggests that significant improvement is possible in all production systems.

CONCLUSIONS and PERSPECTIVES

Production system determines landscape composition and structure, and elements of their eco-efficient use (biodiversity, ecosystem services, productions and incomes/ha/labor unit) more so than does social context.

- ⇨ *The diagnostic method proposed allows for evaluation of farms and landscape eco-efficiency, while setting quantitative objectives for farm development and public policies.*

Eco-efficiency varies among production systems, showing the need for policies to sustain it in the early phases of deforestation and favor eco-intensification at later stages. High variability in each type indicates large potential for immediate improvement.

- ⇨ *Improvement of eco-efficiency is a way to reverse the currently observed relationship between rural development and environment quality. It must be addressed at farm and landscape scales in order to optimize production in plots, biodiversity conservation and ecosystem services, in productive and non productive parts.*
- ⇨ *Diagnostics following AMAZ protocols allows for modeling of interactions and planning with farmers to reconstruct landscapes, with support of public policies and markets (project Amazonia 2030; Fondo Amazônia, BNDES).*

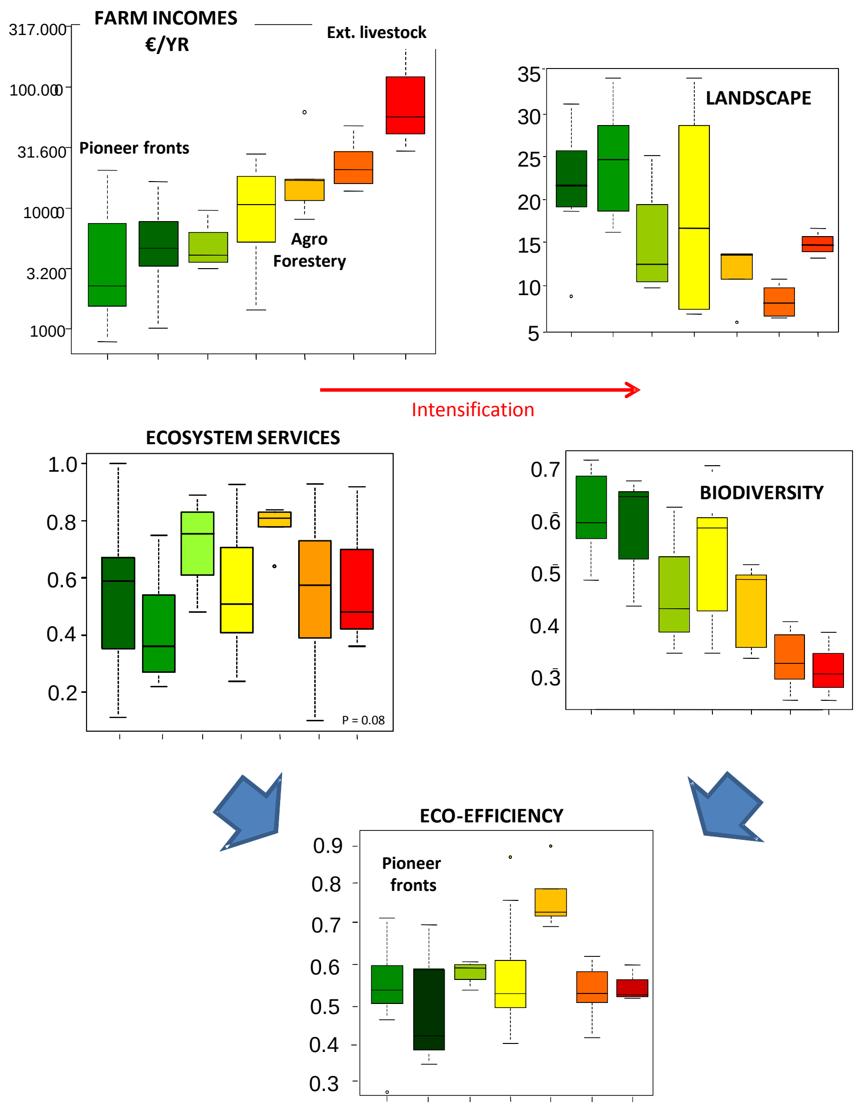
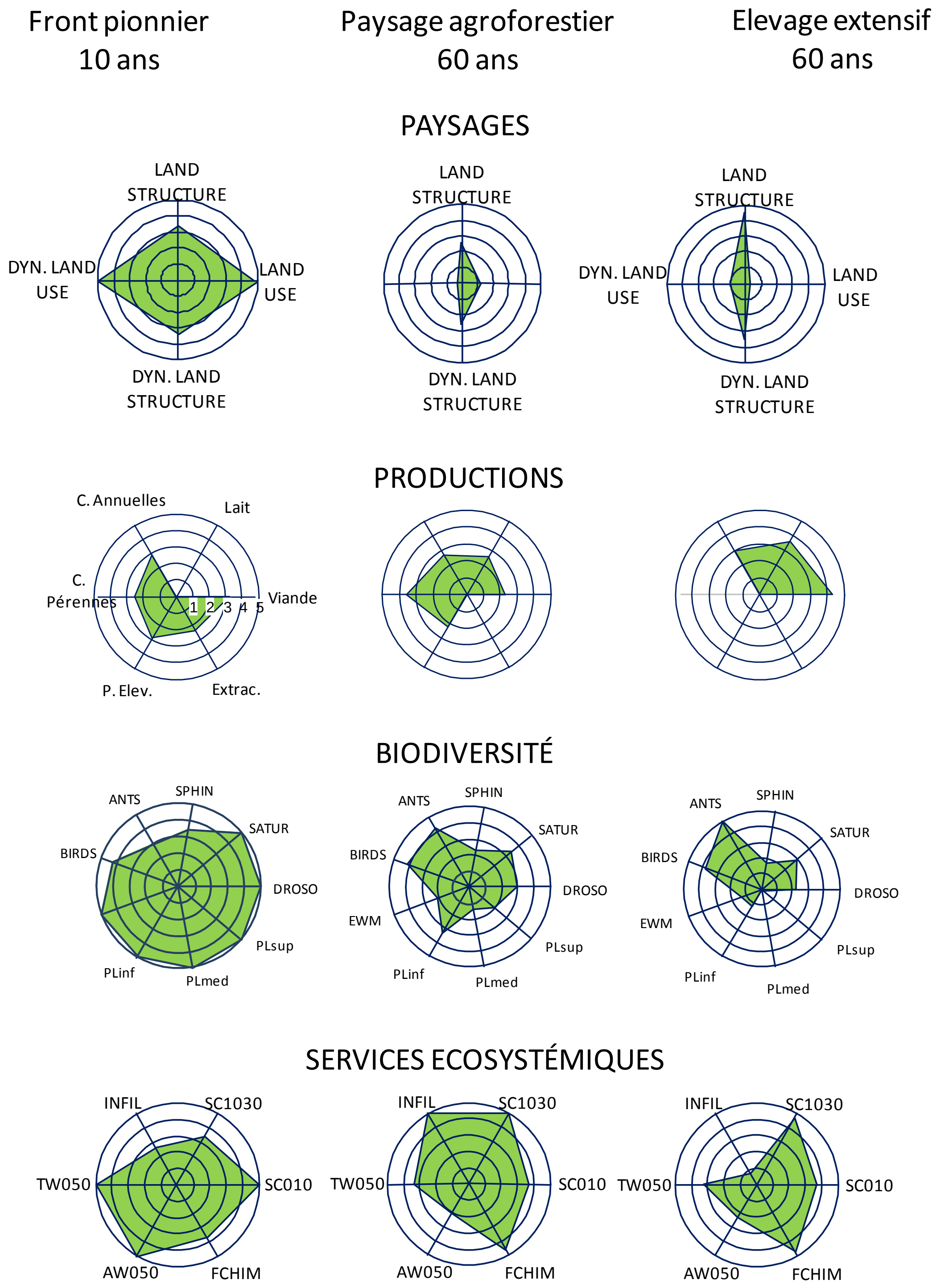
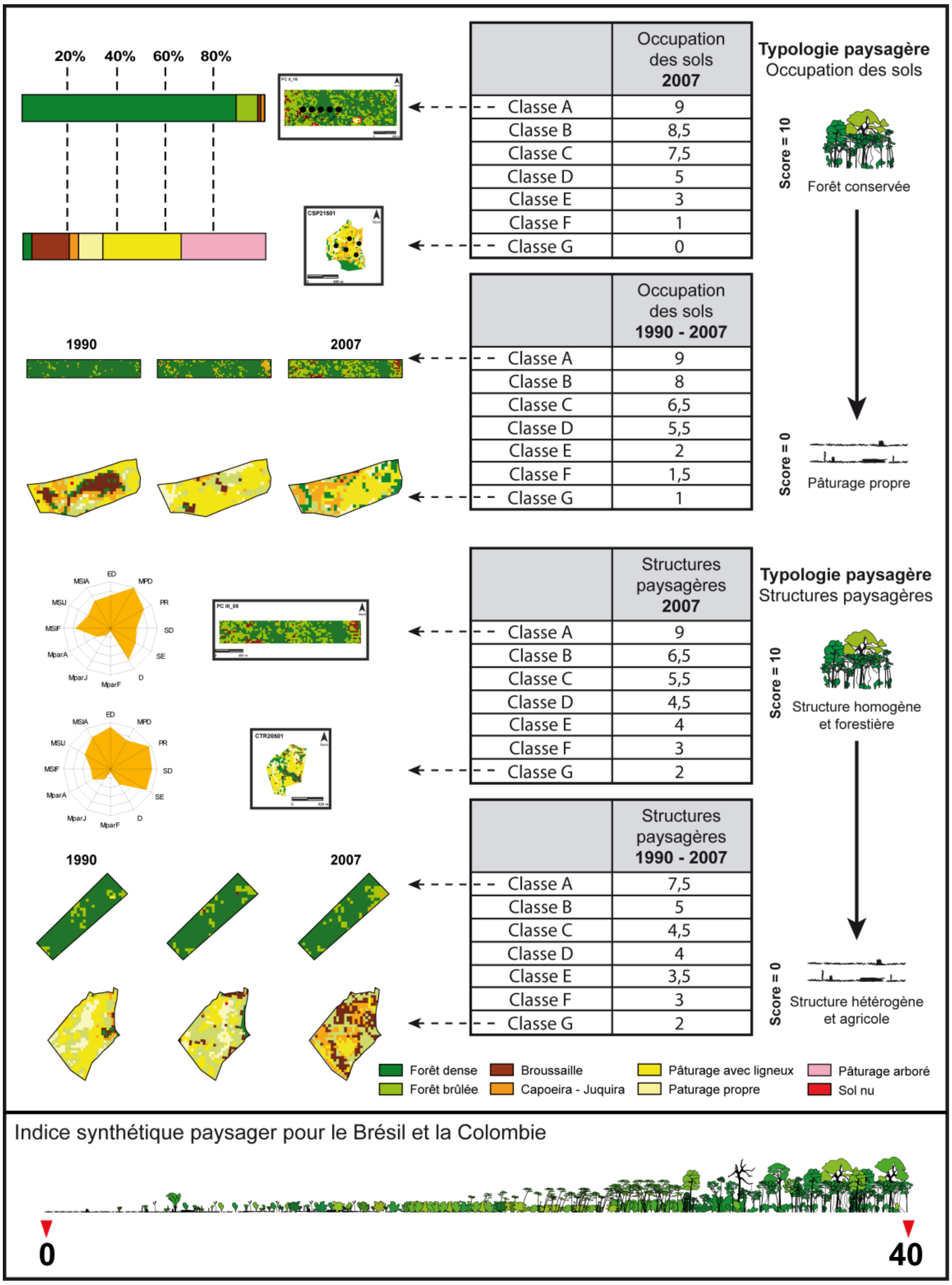


Figure 3 : Changes in values of the Eco-efficiency index and its different terms along a gradient of intensification of land use in the AMAZ sites

Annexe 1 : Valeurs des principales variables décrivant les paysages, les productions, la biodiversité et les services écosystémiques dans les trois types les plus extrêmes de la typologie des systèmes de production. *De grandes surfaces (vert) indiquent les meilleures conditions. Paysages : Indicateurs de composition et de structure e, 2007 et sur la période 1990_2007 (dynamique) ; Productions : Extractivisme ; Biodiversité : PLinf : Plantes de la strate inférieure…. ; Services écosystémiques : INFIL : Infiltration ; SC010 : C du sol strate 0-10 cm ; SC1030 :C dans la strate 10-30 cm ; TW : eau retenue dans la strate 0-50 cm ; AW : eau disponible.*

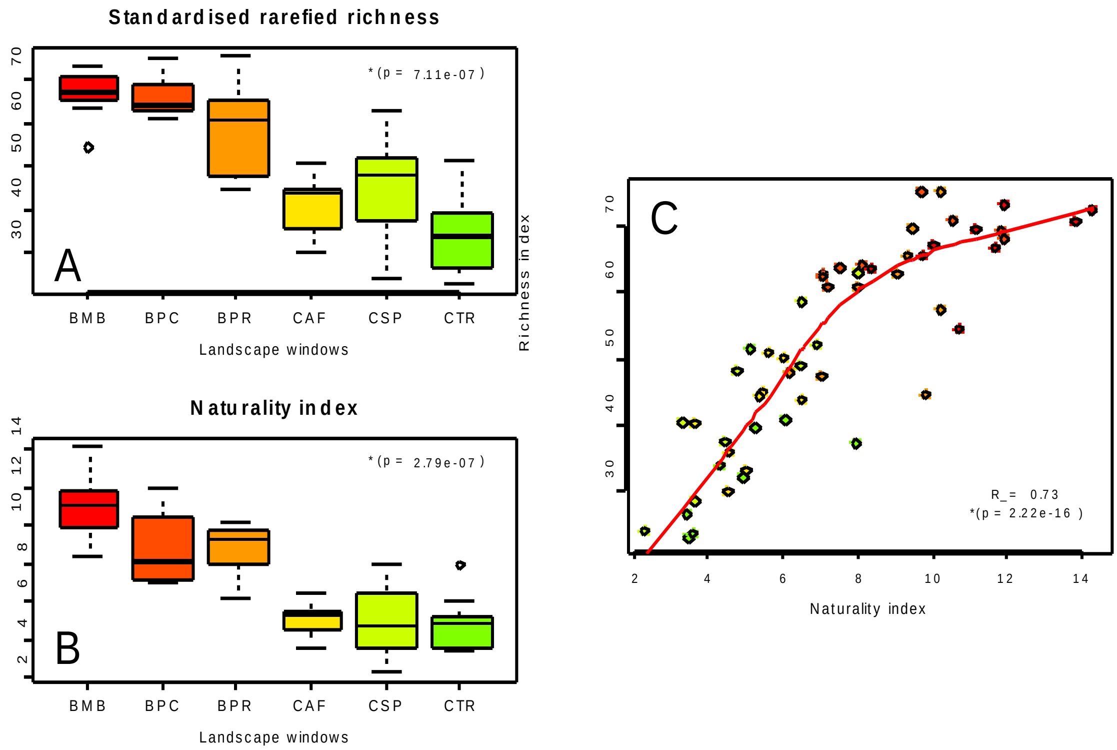


Annexe 2 : Indicateurs de paysage : *Une analyse prenant en compte la dynamique des paysages entre 1990 et 2007 a permis d'établir un indicateur synthétique paysager variant de 0 à 40 qui mesure le degré de conversion du paysage. Un indice de 0 correspond à une ferme qui est constituée de manière homogène de pâturages bien entretenus. Un indice de 40 présente une forêt qui est encore parfaitement structurée. Entre ces deux extrêmes, la valeur de l'indice dépend pour moitié de la dynamique de l'occupation des sols entre 1990 et 2007, l'autre moitié marquant l'impact des dynamiques des structures paysagères sur la même période. (Johan Oszwald).*

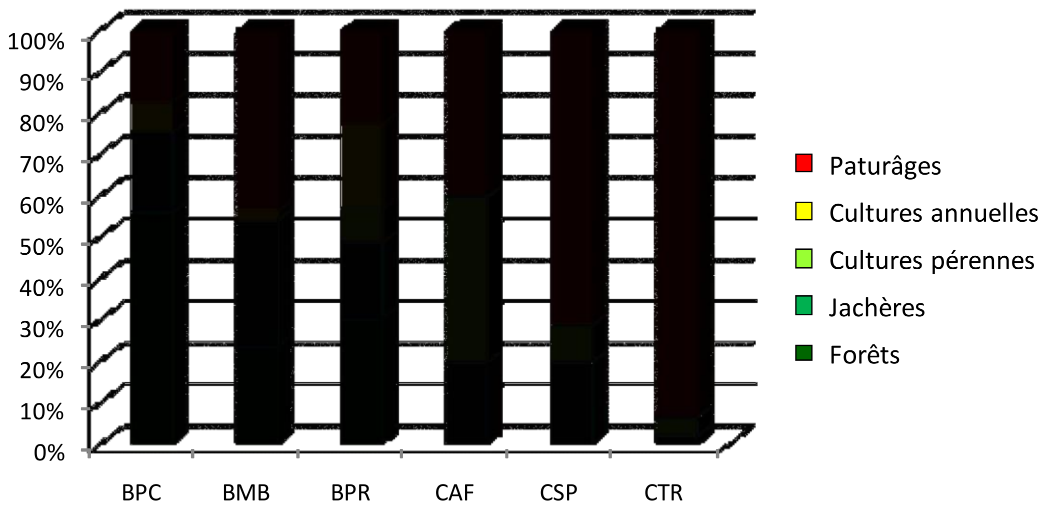


Annexe 3 : Indicateurs de biodiversité.

3.1 : Variation des indicateurs de biodiversité (A) richesse raréfiées et B) indice de naturalité) dans les diverses fenêtres paysagères. Le gradient figuré, depuis BMB à CTR, (en A et B) s'étend des situations à plus faible déforestation au Brésil vers les sites déforestés de longue date et dégradés de Colombie (BMB : Brésil-—Maçaranduba, BPC : Brésil-Pacaja, BPR : Brésil-Palmares ; CAF : Colombie agroforestier ; CSP : Colombie-~~s~~ylvo pastoral ; CTR : Colombie-traditionnel) C: relation entre l'indice de naturalilté et l'indicateur de richesse (facteur 1 del'ACP sur les richesses de tous les groupes).(Thibaud Decaëns).



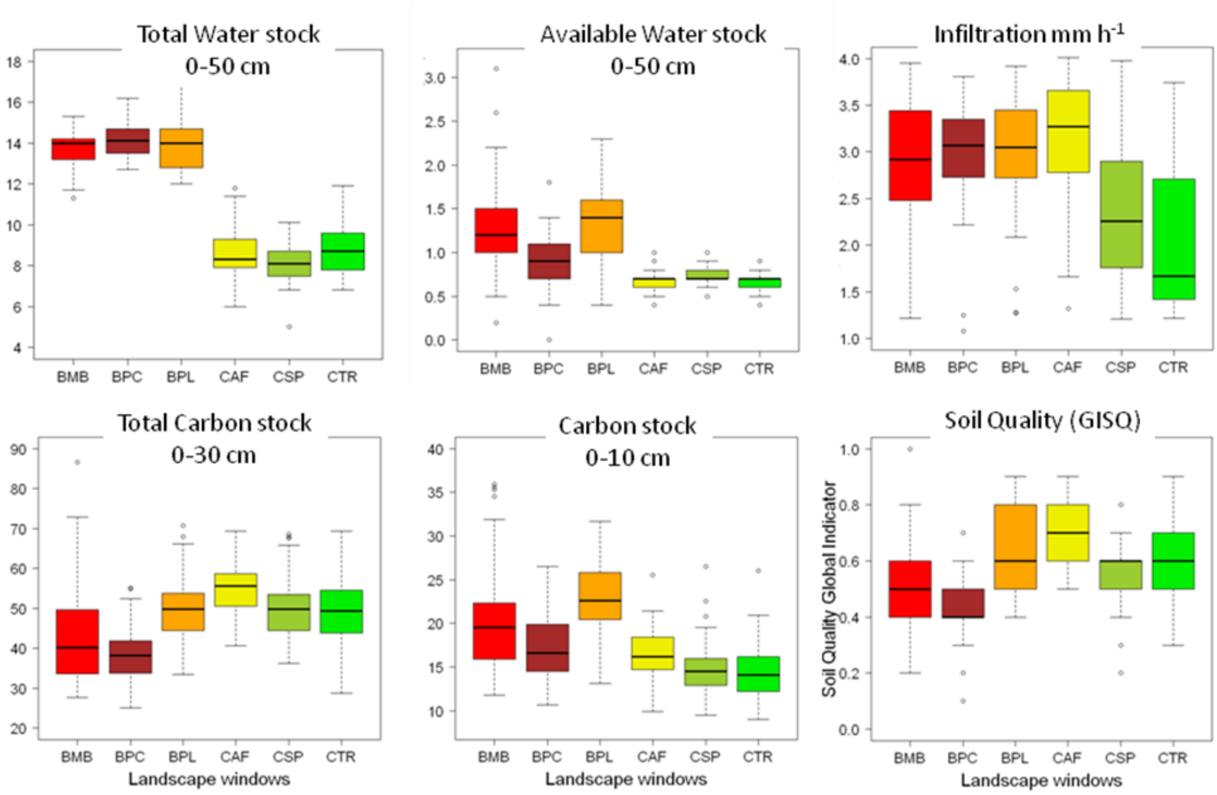
3.2 : Proportion des points échantillonnés dans chaque fenêtre en fonction du type d'usage du sol



3.3 : Nombre de taxons récoltés dans les divers groupes et dans les deux pays

Groupe taxonomique	Colombie n. taxons	Brésil n. taxons	Espèces nouvelles
Plantes (strate inf)	555 sp	1302 sp	Non renseigné
Plantes (strate moy)	320 sp	799 sp	Non renseigné
Plantes (strate sup)	123 sp	305 sp	Non renseigné
Oiseaux	150 sp	238 sp	Non
Saturniidae	36 sp	60 sp	Oui (2)
Sphingidae	33 sp	48 sp	Non
Drosophilidae	40 sp/msp	69 sp/msp	Non précisé
Vers de terre	11 sp/msp	11 sp/msp	Oui (20)
Fourmis	39 gn	40 gn	Non renseigné

Annexe 4 : Services écosystémiques. *Variation des services écosystémiques du sol dans les 6 fenêtres paysagères considérées (BMB : Brésil-Maçaranduba, BPC : Brésil-Pacaja, BPR : Brésil-Palmares ; CAF : Colombie-agroforestier ; CSP : Colombie-sylvo pastoral ; CTR : Colombie-traditionnel). (Michel Grimaldi).*



Annexe 5 : Simulation « REDD » : Effet simulé d'une subvention annuelle de 50$ par ha de forêt, ajusté ou non en fonction de l'indicateur d'éco-efficience de la ferme (appliqué aux fermes qui reçoivent déjà un « revenu non agricole »). (Sylvain Doledec, Patrick Lavelle)

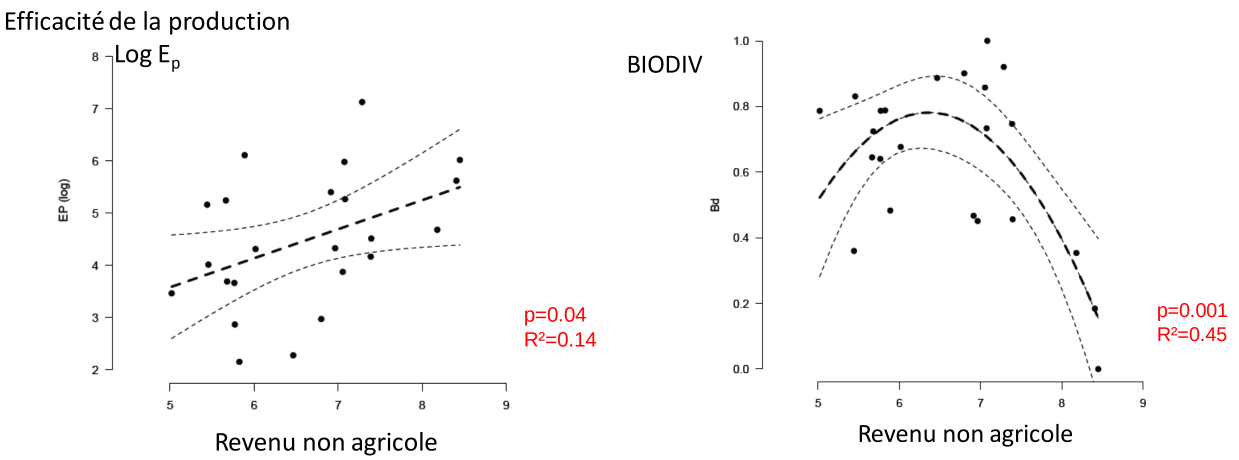


Figure A5.1 : relation entre le revenu non agricole et 1 l'efficacité de la production, 2. La biodiversité. Relations significatives ; R² très élevé pour la biodiversité

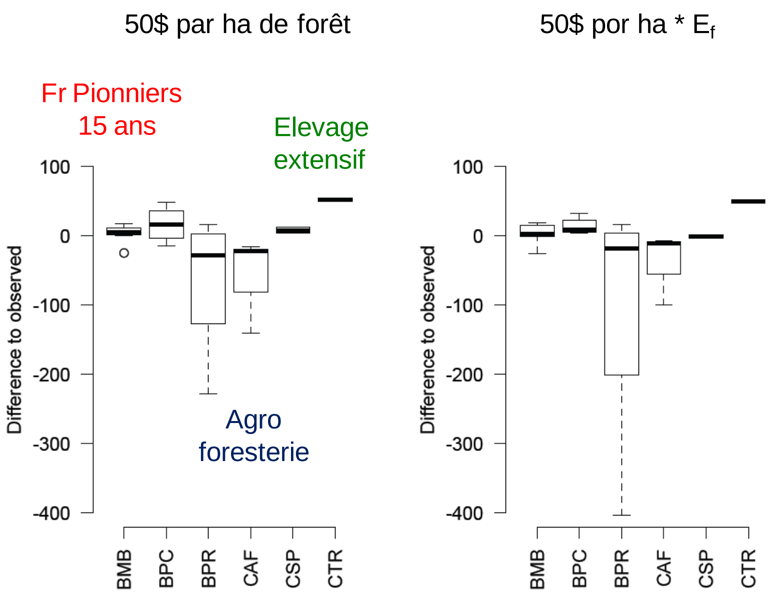


Figure A5.2 : Simulation de l'effet sur l'indicateur d'éco efficience d'une addition au revenu non agricole, basée sur la surface maintenue en forêt (gauche), prenant en plus en compte la valeur de l'indicateur d'eco-efficience Ef. Noter que cette addition au revenu a des effets positifssur les fronts pionniers les plus jeunes (BPC) ou les zones les plus dégradées (CTR) et négatifs dans les zones intermédiaires (diversifié, pauvre).
La prise en compte de l'indicateur Ef, telle qu'elle est proposée ici n'a pas d'effet sensible.

Annexe 6 : Modèle multi agents. *Un modèle a été construit à partir des données des différents WPs pour simuler des scénarios de changements dans les conditions socio économiques que des politiques différentes pourraient provoquer. Le modèle est maintenant opérationnel mais des simulations de scénarios n'ont pu être faites. Elles se feront au cours du prochain semestre et complèteront ainsi les scénarios statistiques (v. annexe 5) générés à partir du modèle statistique.*

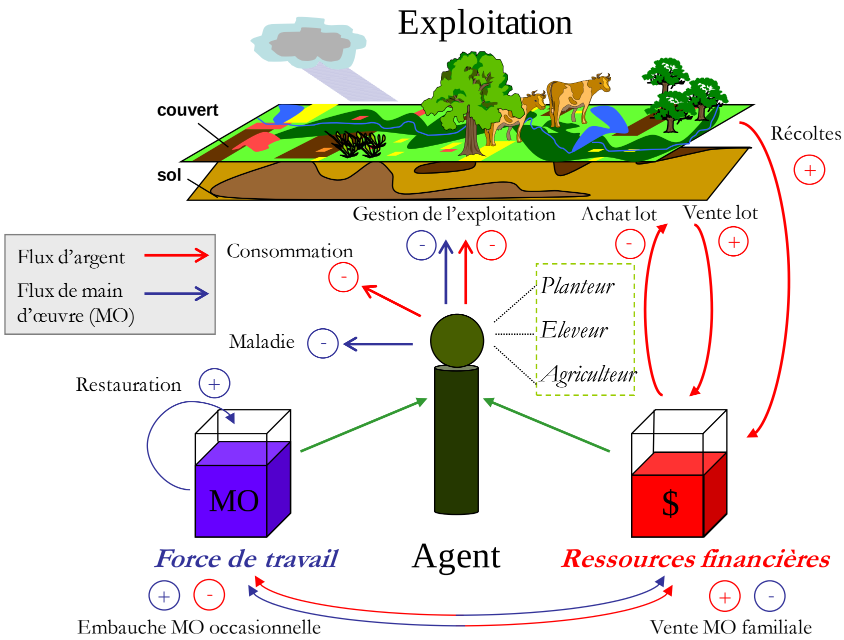


Figure A 6.1 : L'agent « colono »

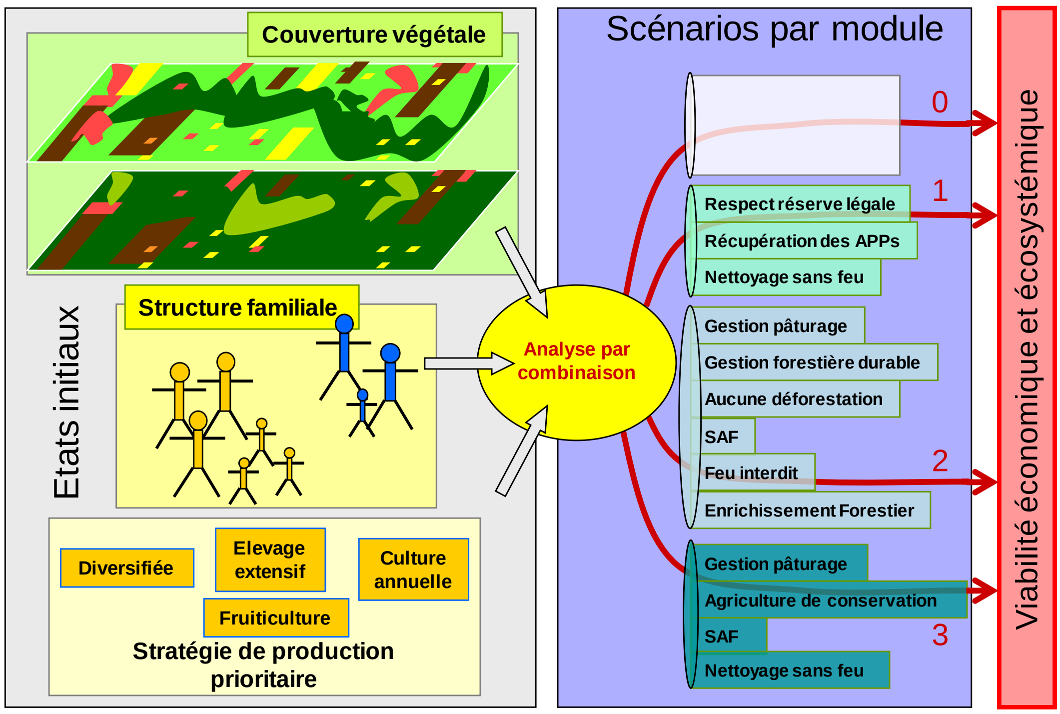


Figure 6.2 : Principe du modèle