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Population and environment relationship: a U-shaped curve hypothesis

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Résumé
Deux conceptions opposées dominent le débat sur le rôle de la démographie dans l'évolution des écosystèmes: les Malthusiens, pour qui toute croissance démographique est accompagnée d'une dégradation de l'environnement et les Boserupiens qui pensent qu'un accroissement de la pression démographique est nécessaire à tout progrès technique et donc ne constitue pas une menace en soi pour l'environnement. Nous nous proposons d'opérer une réconciliation entre ces deux théorie au travers de l'hypothèse d'une courbe en U dans la relation entre population et environnement. En appliquant cette hypothèse à la relation population-couvert boisé, nous la confrontons à une étude de terrain menée à Madagascar et la testons à l'aide d'une simulation par Systèmes Multi-Agents. Enfin, nous examinons les implications d'une telle hypothèse pour le développement durable.

Abstract
The impact of demography on the evolution of ecosystems is dominated by two opposite conceptions: on one hand the Malthusians who argue that demographic growth is directly related to the environmental degradation; on the other hand the Boserupians who think that demographic pressure leads to technological progress and thus doesn't constitute a threat for the environment. We propose to reconcile these two theories through the hypothesis of a U-shaped curve in the population-environment relationship. This hypothesis applicated to the population-tree cover relationship will be confronted to a field study in Madagascar and will be simulated using Multi-Agents Systems. Finally, we draw the consequences of such an hypothesis for sustainable development.

1. The population-environment relationship.

Over the last twenty years, two opposite positions have dominated the debate on the population-environment relationship: the Malthusian one and the Boserupian one.
If we examine the original theory of Malthus as expressed in his *Essay on the principle of population* [8], one sees that he doesn't refer to the environment but to the quantity of subsistence. He thinks that population grows geometrically whereas subsistence grows arithmetically. Consequently, and whatever the original levels of population and subsistence, population will always outstrip the quantity of subsistence. In fine, population level and subsistence level will equilibrate. We must underline the fact that this theory doesn't take into account technical progress and reasons on the Earth as a whole.
With the increasing population, especially in developing countries, over the last fifty years, and the development of environmental consciousness, Malthusian theory has been reinterpreted and adapted to the population-environment relationship. For these neo-Malthusians, every increase of population constitutes a threat for the environment. Moreover, the theory is generally associated with an alarming discourse. They also are at the origin of the carrying capacity concept, which seems synonymous of a fixed maximum population.
At the opposite, the work of E. Boserup [5;6] studies the population-subsistence relationship through technological change. She observes the evolution of agricultural systems in different societies and makes the hypothesis that population growth leads to the adoption of a more intensive agricultural system. If we transpose this to the population-environment relationship, this means that population growth is not a threat in itself for the environment: this is what we generally call the Boserupian position.

Following earlier works by R. Bilsborrow [2;3] and N. Bonneuil [4], we tried to examine the possibility of a complementarily rather than an opposition between Malthusian and Boserupian theories applied to the population-environment relationship. We made the hypothesis of a U-shaped curve: this means that, at first, an increase of the population leads to a degradation of the environment (Malthusian theory); but in a second time, population growth could cope with an increase of the environment quality (Boserupian theory).

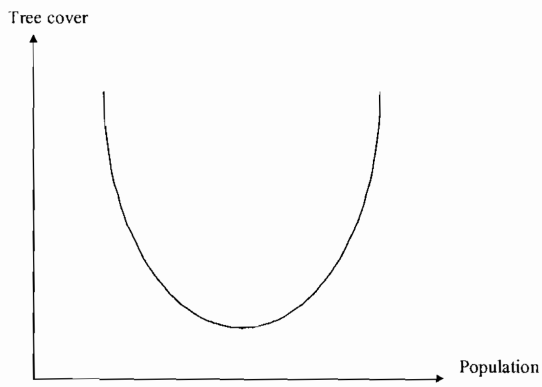

Figure 1

2. Case of the population-tree cover relationship.

We applied the U-shaped curve hypothesis to the relation between population growth and the evolution of tree cover in tropical zones. In this case, the abscissa would represent population pressure (population per cultivated area) or population density and the ordinate would represent tree

Village	Antsirabe	Inara	Varary
Population (1997)	1640	360	1167
Population density (1997)	131 /km²	16 /km²	44 /km²
Market access	Easy	Difficult	Rather easy
Number of surveyed farmers	47	20	46
Total of people in surveyed families	240	98	308

Table 1

cover.
This hypothesis has been tested through three means: the study of the evolution of agrarian systems confronted to population growth through a bibliographical analysis, a field study in Madagascar and computer simulation with Multi-Agents System.

2.1. Theoretical framework

For testing our hypothesis, we chose to study the evolution of agrarian systems confronted to population growth and look at the consequences on forest cover. We first studied shifting cultivation agriculture which is generally considered as the oldest agrarian system still practised in the world [9] and is often accused to be one of the major causes of deforestation.
Shifting cultivation is characterised by a short (one to four years) cultivation period followed by a long (up to twenty years) fallow period which allows regeneration of the soil fertility associated with regrowing of vegetation. Consequently, the agriculturist must regularly change of field before coming back on the first field. This implies that such a system can support only low population densities, estimated from 10 to 35 inhabitants per square kilometre. In this case, population growth (sometimes more than 3 percent per year) can constitute an important perturbation of the system which can't continue if fallow periods are too much shortened. Thus, the system will try to perpetuate itself by adapting to the perturbations: this is the extensification phase (Bilsborrow). While land is the abundant factor and labour is the restrictive one, peasants adopt a strategy of labour minimisation [11] and they will put more land into culture either by going further around the village or by migration to an unoccupied forest zone and creation of a new village. This "mechanism" allows long enough fallow periods and so prevents from a decline of productivity.
This phase is associated with deforestation especially when, with continuous growing population, fallow periods become shorter, the regrowing of vegetation leading only to bush formation[1].
The shortening of fallows leads to a decrease of productivity and then, if all the surrounding land is occupied, i.e. land becomes the scarce factor in proportion to labour, intensification is occurring.
Intensification may not be suitable on all types of land so, according to Ricardo's comparative advantages theory, labour is concentrated on the better land for the adopted technology and some part of the land may be used for tree planting or abandoned to forest regrowing.
Tree planting can also be a mean for marking individual property.
Increasing labour force resulting from growing population allows development of infrastructures necessary to the viability of more intensive systems (for example the construction of terraces for irrigated agriculture).
Another evolution of shifting cultivation systems can lead to agroforests which integrate market-oriented productions [1]

2.2 Field study

The nature of relationships between population and the environment was examined in a field study conducted in Mananara district, on Madagascar East Coast (see figure 2).

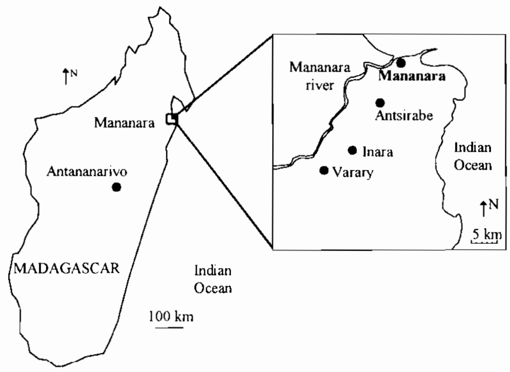

Figure 2

This area has a tropical humid climate, characterised by continuous heat, uniformly high relative humidity and abundant precipitation (2400 mm of mean annual rainfall). The average population density for the entire district is 27 per square kilometre. This is unevenly distributed, ranging from 15 in remote areas to 150 per square kilometre.
Climate and hilly relief are favourable to swidden agriculture, called *tavy* or *jinja*. Forest or secondary vegetation is cut and burnt in November or December just before heavy rains and land is sown with rice. After harvesting, plot can be let lie fallow during 3 to 10 years or used for one more year. Rice cultivation is also practised in rice-fields irrigated by submersion. Planted trees, especially clove-trees and coffee trees, cover some hills.
During the field study, we paid attention to historical patterns of landscape change, to technical aspects of land management and broader conditioning of land use. Three villages (Antsirabe, Inara and Varary, see map) were chosen for their differences in term of demographic pressure, land use and market access (see table 1).
A survey was made regarding land use history: we tried to known successive land uses for all fields of surveyed farmers. For example, on a given plot, we could learn from farmer that forest was burnt in 1950, field was used for shifting cultivation during 20 years and was finally planted by clove-trees. Field areas were established indirectly, through questions about sowing or harvesting quantities. Dates were often determined with references to national, local or familial events. Only recent history (from 1957 to 1997) was taken into account. Data were aggregated using ratio of people concerned by survey. Corrections were made using aerial photographs and satellite image.
In this paper, we present only some results about relationship between population density and forest and tree cover. In the 3 villages, forest area is decreasing and planted tree area is increasing. Relationship between population density and the total area of forest and tree crop is shown (see figure 3).

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1 It is considered that a more than twenty years fallow leads to forest and a more or less ten years fallow leads to bush.

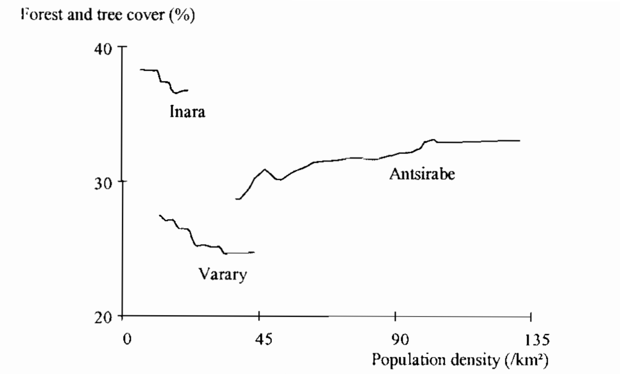

Figure 3

Graph has a U-shaped curve general aspect: under a certain value of population density (around 45 per square kilometre), tree covered area decreases when population increases. But, the three villages have different evolutions because of the context. Here, we haven't deal with the changing economical and political situation that influences how people decide land use changes.
For instance, clove-trees cover large areas in Antsirabe because of easy market access: as products are easily carried and sold, prices are higher than in Varary or Inara and farmers are incited to crop clove. In Inara, primary forest has been protected for some years by a national park. That's why we can imagine that forest evolution in Inara won't be the same as in Antsirabe.

3 Computer simulation

For testing the U-shaped curve hypothesis, we made simulations using Multi-Agents Systems. Multi-Agents Systems are used as a laboratory in which we can conduct different experiments. We create an artificial world composed of different agents where "each agent is represented as a computerised independent entity capable of acting locally in response to stimuli or to communication with other agents" [7]
The simulation takes place on a grid composed of cells.
In our model, we had three types of agents:
The cells represent the resource (i.e. forest plots or fields) which is characterised by levels of vegetation and fertility. Fertility declines when the field is cultivated and increases when it is left to fallow. The adopted technology determinates the speed of both decrease and increase of fertility. Vegetation also regrows when the field is left to fallow if technology is shifting cultivation. In the model, we used only two types of technology: shifting cultivation and irrigated agriculture (without fallow period). For shifting cultivation the indicator of fertility level can take a value between 1 (very bad) and 5 (very good), the same for vegetation. When the field is cultivated, fertility indicator decreases of one point each year, and vegetation indicator remains 1. When field is not cultivated, fertility indicator is incremented of 0.4 each year and 0.2 for vegetation indicator. For irrigated agriculture, we supposed that fertility remains constant.
Peasants which exploit the resource under given constraints depending on the adopted technology. The fertility of the exploited field and the adopted technology determinate the production which modify the satisfaction level of the peasant. For shifting cultivation, production indicator is calculated as (20 × field fertility); for irrigated agriculture, its value is 200 and remains constant. Peasants will only change technology if their satisfaction level decreases under a "critical level". This means that the peasant won't choose a technology regarding the potential production it offers, but he will always use the more labour-saving technology unless production is too low.
- Villages which represent the collective level. They have a territory, defined by a radius around them, in which peasants can evolve. They also collect information on the production of the peasants.
This describes the interaction principles between the different agents of our model. After this, simulation is running without outside intervention.
In all simulations, we implemented a constant population growth of 3 percent per year, each year being a step in the simulated world.
We shall now describe the evolution of the system.
At the beginning, the only technology is shifting cultivation: peasants exploit a plot until fertility becomes too low and then leave it to fallow. During fallow, vegetation is regrowing and so potential fertility. Peasants, when looking for a new plot, must arbitrate between the distance from the village and the potential fertility of the plot. With increasing population, peasants will exploit plots further and further from the village. But they can't go to far from the village and so, they will come back on plots on which fallow period has not been long enough to generate a maximum fertility. Thus, production will decrease and when it reaches a "critical level", part of the population will emigrate to a new forest zone and create a new village. This is the extensification phase.
When production decreases and migration is no longer possible (all the space in our virtual world is occupied), peasants have to adopt a new technology. They will select from their fields one where they can develop a more intensive system (some constraints can be the distance from the village or the topography). The other fields are then abandoned (or converted to plantation). Thus, the intensification phase is accompanied by an increase of the tree cover.

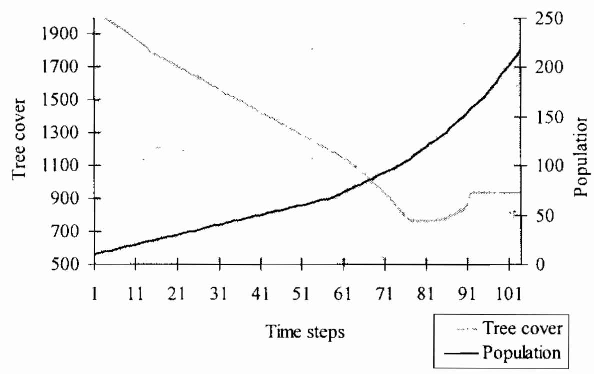

Figure 4

Figure 4 shows the evolution of population and tree cover. The increase of tree cover seems limited in our simulation for a few reasons. First, the increase of population is independent and constant (3 percent per year). We didn't implement the possibility of migration outside the system (urban migration for example). Moreover, we didn't take into account the division of labour and the development of non-agricultural activities.

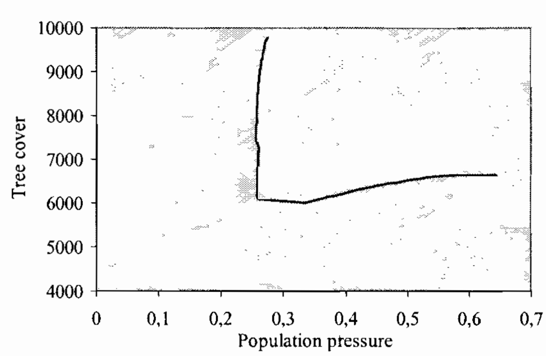

Figure 5

Figure 5 shows the relation between tree cover and population pressure in the time. At first, population pressure remains more or less constant whereas tree cover decreases. In a second time, population pressure and tree cover both increase. Deforestation corresponds to the extensification phase: putting lands into culture further around the village and migration to unoccupied zones appears as a mean to keep population pressure constant. But more than this, it means preserving the social system (the agricultural system being considered as part of the social system) from the perturbation constituted by population growth.

3. Implications for sustainable development

Discussions among environmentalists are frequently biased by strict opposition between two main point of view. On one hand, the "Malthusians" assume that the population growth is responsible for environmental degradation and poverty. A type of "vicious circle" called "nexus" by the World Bank. On the other hand, "Boserupians" assume that the demographic growth is the main force that drives agricultural progress. From a Boserupian point of view, a high population pressure is a *sine qua non* condition for irrigation systems to be viable, because a high population pressure is needed for the management of the landscape. The U-shaped Curve hypothesis goes beyond this opposition and illustrate the possible relevance of the two points, on each side of the Curve. This is the main scientific implication of the U-shaped Curve. More important, there are some implications for sustainable development.

It is highly desirable to no longer confuse demographic density and demographic pressure. The density refers of the division of the population by the surface, is independent of the nature of the production system. The pressure refers to the division of the population by the cultivated surface. We call absolute pressure the population by cultivated surfaces, and relative pressure, the population divided by the cultivated surfaces + the fallows. The concept of pressure, under such definitions, becomes an indicator of intensity. A low pressure means a high capital intensity ; a high pressure means a high labour intensity.
It seems relevant to assume that the forest cover increases together with the development [10] as well as because of agriculture intensification and urbanisation.
If the U-shaped Curve hypothesis is to be verified, emphasis must be on the lowest part of the U, where irreversibility is a part of the process; hunger, emigration, usually occur which reinforce the Malthusian point of view. But the issue no longer is to "struggle against" demographic growth. The issue becomes: how to shorten the bridge between left and right sides of the U-shaped Curve, in order to minimise social and environmental costs.
When there is a lack of Capital, it may be worth to create infrastructures and incentives for the population to concentrate so as the production system becomes more intensive.

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