Title: The Maya Collapse: A study on resilience and collapse of societies using the system dynamics approach.
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Abstract

The general purpose of this paper is presenting a systemic framework for assessing resilience in social-ecological systems based on the system dynamics approach, which is an especially useful methodology to model complex systems. In order to show how to assess the resilience degree of a system, a simple system dynamics model for the collapse of Maya civilization, an extreme case of loss of sustainability, is built. The specific purpose of the model is twofold: a) to determine the minimal set of assumptions required to produce the loss of resilience that drove the late classic Maya civilization to collapse and b) to underpin a discussion of resilience and collapse in generic economic growth processes.
Key-words: resilience, system dynamics, economic growth, Maya

Resumo

O objetivo geral do artigo é apresentar uma metodologia para avaliar o grau de resiliência de sistemas sócio-ecológicos baseada na abordagem de dinâmica de sistemas, a qual é especialmente útil para modelar sistemas complexos. Para mostrar como avaliar o grau de resiliência de um sistema, um modelo sistêmico dinâmico simples para o colapso de civilização Maia é construído. O objetivo específico do modelo é duplo: a) determinar o mínimo conjunto de pressuposições necessário para produzir a perda de resiliência e finalmente o colapso de civilização Maia e b) estabelecer os fundamentos sobre como utilizar o conceito de resiliência em estudos sobre crescimento econômico.
Palavras-chave: resiliência, dinâmica de sistemas, crescimento econômico, Maias.

Classificação JEL: O43, O11
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1 – Introduction

A vast body of literature on the subject of efficient governance institutions for human communities using common pools of natural resources has been accumulated in recent years (for a survey of this literature, see Ostrom, 2005, chap. 8). According with that literature, the most critical aspects of the problem are related to the idea of resilience, a concept not traditionally used in studies on economic growth. Such studies nevertheless, for reasons that will become clear later in this paper, should likely emphasize the conditions for resilience or sustainability[1] as well as the requirements for growth igniting. Broadly speaking, the concept of resilience refers to the capacity of a social-ecological system – that is systems which include human beings and their environment - in preserving its functioning in the presence of exogenous change (Holling, 1973). The problem with this concept, as suggested for instance by Gunderson and Holling (2001), is that it is been hard to find simple measures for resilience as far as social-ecological systems are complex ones, that is involve, among other characteristics, the properties of non-linearity and self-organization. The general purpose of this paper thus is presenting a systemic framework for assessing resilience in social-ecological systems based on the system dynamics approach which is an especially useful methodology to model systems presenting the properties above.

Many works have considered the loss of resilience mostly as a consequence of surprise-driven crises that affect system´s agent's ability to cope with sudden dramatic perturbations, such as in the case of unusually severe droughts (Weiss and Bradley, 2001), or environmental disturbances resulting from resource mismanaging (Diamond 2005). The problem with those studies is they do not develop explanatory arguments that link cause clearly to effect (Tainter, 2000: 342) Systemic analysis suggests that link can be very subtle and complex. Bueno (2009) and Bueno and Basurto (2009), for instance, have shown that the process of loss of resilience takes place when the system crosses a critical quantitative threshold – a tipping point - even for a small margin, which means that the loss of resilience might be unnoticeable to the stakeholders. Beyond the tipping point, social- ecological systems flip to a different state in which their dynamics are dominated by positive feedback loops which makes the process cumulative. The dominance of such loops – labeled as death spirals – is therefore an identifiable signature for the loss of sustainability of a particular social ecological system.

In order to show how to assess the resilience degree of a system as the distance from its tipping point, we shall present a simple system dynamics model for the collapse of Maya civilization, an extreme case of loss of sustainability. The reason for choosing this apparently bizarre example (for an economic paper) is that, as we shall argue later, it can shed new lights over growth and collapse processes when approached under system dynamics lens. Despite the huge advances in our knowledge of Maya society specialized literature has provided, it seems that we may expect little further progress from traditional approaches in the understanding of basic questions regarding why that marvelous civilization lost sustainability and eventually collapsed altogether between 800 and 900 AD. The reason for this is that, at least beyond some point, mathematical modeling seems to be the safer way to clear explanations of logical flaws and to identify the critical assumptions required for reaching unambiguous conclusions. Hence, the specific purpose of the system dynamics model to be presented in section 3 is twofold: a) to determine the minimal set of assumptions required to produce the loss of resilience

[1] As the meaning of both concepts can be assumed for practical purposes as similar, those terms are used interchangeably henceforth.

that drove the late classic Maya civilization to eventually collapse and b) to underpin a discussion of resilience and collapse of economic growth processes.

The remainder of the paper is organized as follows. In Section 2, the literature on the Maya collapse is reviewed and a plausible systemic explanation for the event based on that literature is sketched. In Section 3, a systemic dynamic model based in that explanation is built. Section 4 presents the main results, Section 5 discusses them and Section 6 concludes the paper, suggesting that the system dynamics methodology may be a useful tool for economists interested in studying economic growth.

2 – The Maya Collapse: a brief literature review

The dominant present view on the Maya Collapse, following the modern literature on the collapse of civilizations which prefer to explain those processes by the occurrence of extreme events (Tainter, 2006), is that it would have been driven by a unusual drought about 800 AD. Field evidence, however, does not always fit well that explanation; a number of Maya sites survived the worst years of drought while others collapsed before those years. Thus it would seem fair to think that when we have something so complex as Classic Maya society it's going to take either a complex string of events to drive it to an end (apud Pringle, 2009), or a number of different models to explain different processes (Lucero,1999). Specifically, drought would have triggered a number of other processes, such as institutional failures, which would have brought Maya civilization to collapse. For example, drought might have increased deforestation which would have aggravated climate change according a positive feedback loop, as posed for instance by Jared Diamond in its famous *Collapse*. That last explanation however, at least implicitly, also assumes that it was necessary a unusual strong shock to lead Maya society to collapse which has been hard to verify in field studies for a number of important Maya sites. We shall not attempt to evaluate the merits and problems of each one of those explanations, rather we shall attempt to demonstrate that great part of the mystery of the process comes from the fact that collapses occurred moved by an essentially simple dynamics of which we can gain some insight by adopting a systemic approach as below.

In the words of one of the most important Mayanists, Michael Coe (1971), "Almost the only know factor about the downfall [of the Maya civilization]… is that it really happened. All the rest is pure conjecture". But that was a provocative way to put the question; we indeed know a little bit more about the process today. What we know with certainty from the observable archeological record is: a) the Maya collapse meant a general failure of elite-class culture, involving mainly the abandonment of administrative and residential structures, cessation of erection of monuments, cessation of the use of calendrical and writing system, and in consequence the disappear of the elite class; b) there was a rapid depopulation of the countryside and the ceremonial centers, and c) the process occurred in a relatively short period of time – from 50 to 100 years between 800-900 AD. A plausible systemic interpretation for Maya collapse is as follows.

Maya economy was an essentially human-powdered one. That feature, on the one hand, explain the relatively low productivity it presented even its agriculture had been able to introduce a number of techniques such as terracing of hill slopes and array of canals and drained or raised fields. On the other hand, the logistic difficulty in carrying food in longer military campaigns, due to the lack of other sources of power as horses, explains why Maya society remained politically divided among small kingdoms constantly at war with each other.

When the population in the Pre-classic became sufficiently dense (between 400 BC and 50 AD) the solution for food shortages become raid neighboring groups for filling the deficits. The long term tendency of introducing the more efficient techniques above mentioned were not permanent solutions to food shortage crisis because they induced ulterior increasing in population. War, therefore, remained as a permanent option. But once a competitive system among the Maya kingdoms was established the best strategy for any Maya polity was deterrence.

Massive labor consuming investment as the impressive monuments built mainly in the late classic period was a very effective way to communicate the relative strength of political centers. The sculptural and painted art showing terrifying treatment of enemies are a clear signal that monument building could be understood in the same way as a form of signalizing to visiting emissaries of potentially competitive centers the capacity to retaliate eventual invasions.

But the spending in monuments had probably the function of attracting unattached rural population as well. The Maya of the Classic period were engaged therefore, as remarked by Tainter (1988:.173), “in a system of competitive relations in which advantage would accrue to those centers that were larger, that invested more in competitive display, and that could mobilize greater population.”

The concentration of population in those centers, however, had the effect of making worse the deficiencies of the Maya agriculture due to the degradation of the agricultural landscape. Yet they managed to implement techniques that delayed the decrease of productivity that degradation implied. In the Copán Valley, for instance, the population rose to a peak estimated at 27000 people at A.D 750-900. Archeological data show that the different types of habitats were occupied in a regular sequence. By the year A.D 650 people began to occupy the hills, using terracing agriculture, which was likely one of the prime means by which Maya tried to increase agricultural production. Terracing, besides, is a very effective way to check erosional processes and to promote soil buildup and limit nutrient losses by conserving inorganic particles and leafy matter that would normally be washed downslope by rains.

Insofar as population increased, therefore, the entire system became more interdependent. The viability of raised fields, for instance, depended increasingly more on slopeland terracing for checking erosion once large parts of forests had been cleared. As far as the Mayan agriculture was human-powered, vast amount of labor were required for maintaining the system and any factor which limited the labor supply would have serious repercussion in its viability. Santley et al. (1986: 146) summarize this point as follows:

> “ It is conceivable, then, that the Late Classic collapse was the direct result of farmers making economically short-term decision which were dysfunctional on a long-term basis. Reductions in the area of slopeland cultivation would have exposed large portions of the landscape to the effects of those very degradation process which terracing was designed to retard. One thing we know about terrace systems is that they require continual maintenance. Lack of maintenance commonly results in breaches in the terrace wall, and once a break occurs, the erosion of soil from behind the embankment is rapid and assured. Often as well, the smallest terraces are located upslope, due to the increase in slope angle, and these typically are the first to be abandoned because more work is required per unit of cultivated space to maintain their embankment walls. Inadequate maintenance upslope will thus undermine the viability of components of the terrace system downslope. The erosion of slopelands will greatly accelerate rates

of sedimentation in bajos and lakes. Increased sedimentation clogs canals which drain raised fields, ultimately raising the water table as well as reducing the biological productivity of micro-flora used as mulch. These processes would have had the effect of decreasing the area devoted to raised field agriculture, as well as of limiting the productivity of those fields which were still under cultivation. The erosion of topsoil from slopelands would have also impeded patterns of plant succession, thus impairing forest regrowth. Seral development generally occurs quite rapidly in the humid tropics, with dense woodland (but not climax) vegetation returning within twenty years. Succession rates, however, may be significantly retarded if edaphic conditions are greatly altered by habitat destruction. The restriction of many species of seral and climax vegetation to refuge habitats on the margins of cultivated zones would have further slowed forest regrowth. It may consequently have take decades, if not longer, for normal patterns of seral development to become firmly established. Thus, what was formerly a productive agrarian landscape may have been quickly transformed into an agricultural wasteland, so to speak, once sufficient labor was no longer available to dive the subsistence economy".

It was exactly that reduction on the availability of labor what happened in the Late Classic. By the end of this period, the production of all foodstuff was strained. The staples which were grown were rich in calories but very poor in other nutrients. The nutritional problems resulting have great impact on the structure of human populations. At the site of Copán, but also in several others as documented by archeological surveys, there happened frequent surges of severe infectious and nutritional diseases. There was, for instance, high frequency of several varieties of anemia and scurvy resulting of Vitamin C deficiency. Male stature, in consequence, decreased between the Pre-classic and Classic periods, while life expectancy declined abruptly in the late Classic. The lower class population, as a whole, was unhealthy, and experienced a high number of deaths among older children and adolescents.

Growing rates of mortality and of mal-nourished individuals in the population decreased the availability of labor, and in the end of the Late Classic the Maya economy was severely strained by the lack of manpower necessary to maintain the structure of its agricultural system.

The reduction in food availability in all Maya kingdoms made necessary intensifying the deterrence strategy of monuments building, which aggravated the shortage of labor for agriculture, setting in action what we may label as a death spiral: the degradation of the terraces led to sharp losses of productivity in raised fields and to the intensification in monument building, which reinforced the degradation of terraces due the reduction of labor available. When the death spiral started to dominate the system dynamics the collapse was rapid and unavoidable. The diagram to be presented in Figure 1 below will illustrate the whole process.

3 – The model

3.1 – Methodology

The fundamental ideas of this paper come broadly from the field of system dynamics that originated in the 1960s with the work of Jay Forrester and his colleagues at the Sloan School of Management at the Massachusetts Institute of Technology. System dynamics allow the construction and analysis of mathematical models and simulation scenarios that identify critical feedbacks influencing systems (Sterman, 2000). System dynamics has been increasingly used in a wide variety of environmental and resource settings (Cavana and Ford, 2004) such as global environmental sustainability (Meadows et al. 2004), water resource planning in irrigation systems (Sengupta et al. 2001), and ecological modeling (Costanza *et al.,* 2001; Costanza and Wainger, 1993). A detailed description of system dynamics methodology with special emphasis on social ecological systems is given in Ford (1999) and a very readable general explanation about how to apply it can be found in Saysel *et al.* (2002). A earlier systemic dynamics model for the Maya collapse, finally, is provided by Hosler et al. (1977).

3.2 – The model

Figure 1 in the next page depicts the simplified stock-flow structure of the complete systemic dynamics model used in the simulations carried out in the next section[2]. Population is a stock or level variable which accumulates the value of the rate variables *births* and *deaths*.

The population dynamics is given by the following equation:

$$\frac{d\,Population}{dt} = births - deaths$$

$$births = Population.\times\% females.\times fecundity\ rate$$

$$deaths = Population \times mortality\ rate$$

Where we assume that females are 50% of the population and that the average number of children by woman is 2,5, that is we assume the fecundity rate is 0,0625, considering an average 40 years life span in Maya sites (fecundity rate is given by 2.5/40).

Mortality rate is modeled by using the effect variable "effect of food availability on mortality". The way to do that is building a table or lookup variable as follows:

mortality rate = effect of food availability on mortality (per capita food availability)*base mortality rate

and

base mortality rate = 1/average life span
effect of food availability on mortality= ([(0,3)-(1000,1)],(100,3),(300,1.5),(450,1),(1000,1))

[2] The complete VENSIM model is available upon request to the authors.

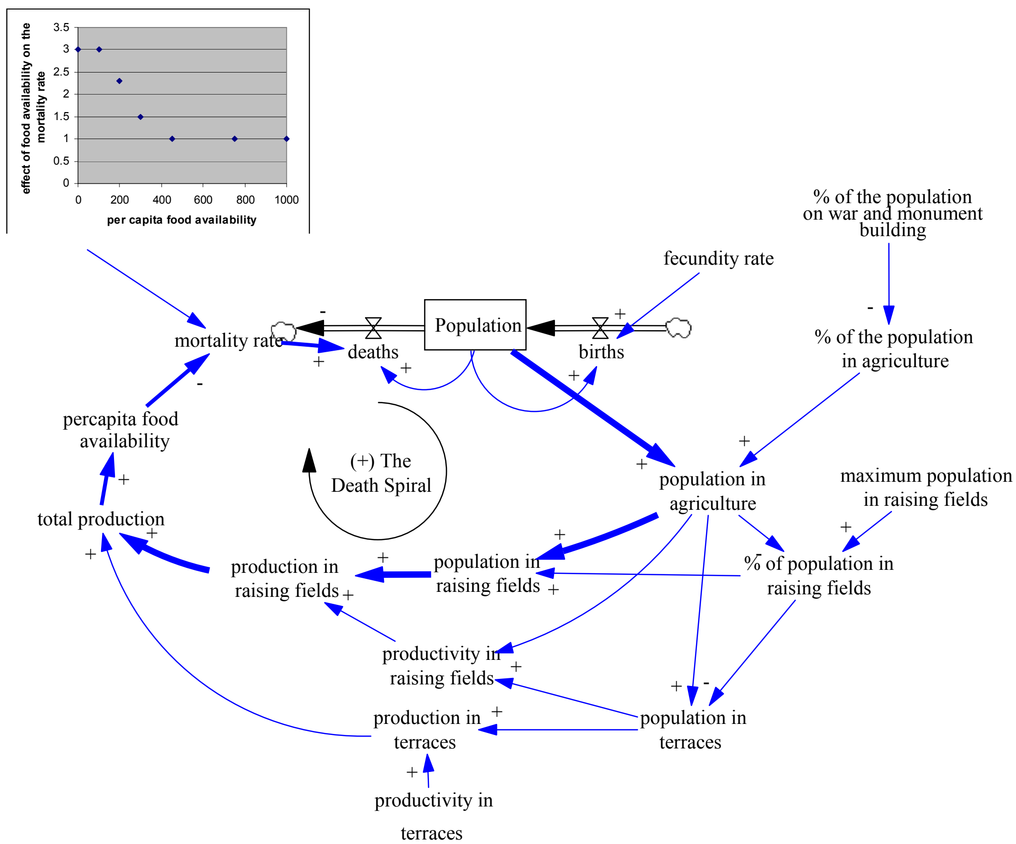
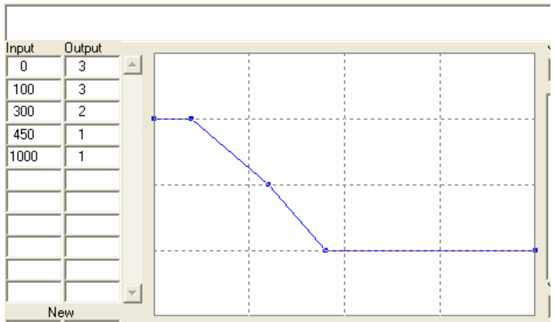


Figure 1: The dynamics of the collapse of Maya civilization

The variable "Population" inside the box is the only state variable in the system, while the others are either parameters, like the "maximum population in raising fields", or auxiliary variables, like the "% of the population on war and monument building". Positive signs indicate that the variables move in the same direction and negative signs, in the inverse direction. Thus "Population" increases with "births" and decreases with "deaths". The double arrows ended by a cloud delimit the boundaries of the system, that is what is assumed as endogenous or exogenous to it. The sign (+) inside the "death spiral" loop arrow indicates the presence of a positive or self-reinforcing loop. Hence, increases (decreases) in "Population" increase (decrease) births flow and thus the "Population" next period. The sign of the loop, that is whether it is of self-reinforcing of balancing type, is obtained by multiplying the signs of the relationships included in the loop. The basic dynamics of the system is as follows. Environmental degradation brought about by population growth led to more frequent wars among Maya kingdoms and to an intensification of monument building as a deterrence strategy. This relationship is modeled by a gradual (exogenous) increase in the percentage of the population involved in wars and monument building from zero to 11% in the late classic period; that is the exact relationships between environmental degradation and propensity to war is out of the system's boundaries. That implied a gradual reduction of the population involved in agriculture, at first in the terraces where productivity was lower. The gradual abandonment of the terraces increased erosion on slopelands which clogged irrigation canals, decreasing the productivity and production (when the population began to decline) in the raising fields. That eventually led to shortages of food and consequently to increasing mortality rates. The positive feedback loop labeled as "the death spiral", highlighted by thicker lines, closes with the reduction of the population which leads to further reductions in agricultural population.

Graphically the table function assumes the following form

Figure 2: The relationship between food availability and the mortality rate multiplier



Input = food per capita availability, Output = mortality rate multiplier

That is, if for instance the availability of food (corn) is 450 kg/year/person, base mortality rate will be multiplied by 1 and by 2 if the availability of corn is 300 kg/year/person.

The availability of food depends on the population size, the parcel of that population allocated in the agriculture, and the productivity of farmers in more and less productive lands. Farmers prefer producing in more productive lands, that is in raising fields, but there is a limited amount of those lands available. Once that limit is reached, extra population must occupy slopelands and produce in terraces. The part of the population working in terraces is giving by:

population in terraces = population in agriculture * (1- % of population in raising fields)

% of population in raising fields = IF THEN ELSE (population in agriculture<=maximum population in raising fields, 1, maximum population in raising fields/population in agriculture)

That is, if the population is lower or equal to the maximum population that raising fields can support, farmers will use only those more productive lands. All extra population will be allocated to terraces.

Population on war and monument building sector diverts population from agricultural sector and hence can trigger a process of collapse insofar as the population loss in agriculture decreases production in terraces enhancing erosion processes. This variable is exogenously given by the equation:

% of the population on war and monument building = RAMP(0.0025, 700 , 780)

Which means that the part of the population involved in those sectors increases by 0,25% a year from 700 to 780 AD, starting in zero and reaching the maximum of 20% of total population in the last year.

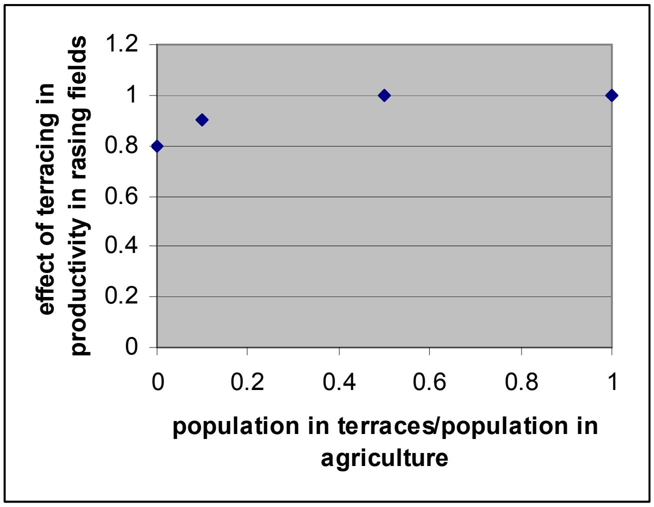
The effect of the decrease of population in the productivity in raising fields is modeled as:

productivity in raising fields = effect of production in terraces on productivity in raising fields (population in terraces/population in agriculture)*(base productivity in raising fields)

and

the effect of production in terraces on productivity in raising fields, by the lookup function presented in Figure 3.:

Figure 3: The effect of terrace production on the productivity in raising fields

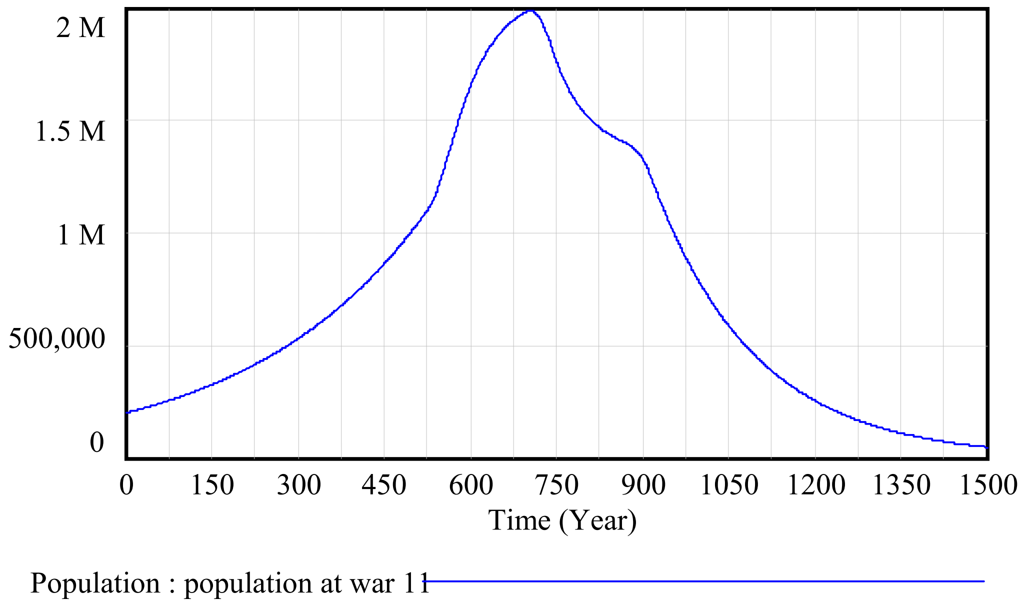


The basic dynamics of the model is as follows. Population growth leads to increasing food production at a constant per capita rate. When terraces begin to be used, average production decreases since productivity there is lower. Per capita food availability then decreases, leading to increases in mortality rate and thus in the flow of deaths. When the flow of deaths overcomes the flow of births, population starts to decline. If the process is unchecked by further mortality reduction, terraces will begin to be abandoned. As terraces are abandoned, erosion will take place decreasing productivity in raising fields and per capita food availability. The death spiral will dominate the system's dynamics, leading the system to collapse, if the mortality rate reaches a threshold in which the flow of deaths becomes permanently larger than the flow of births. Systemic thinkers often use the metaphor of a bathtub to illustrate how a system can lose sustainability. If the drain flow (that is the flow of deaths) becomes larger than the tap flow (the flow of births) the bathtub will necessarily be empty at some point .

4- Results

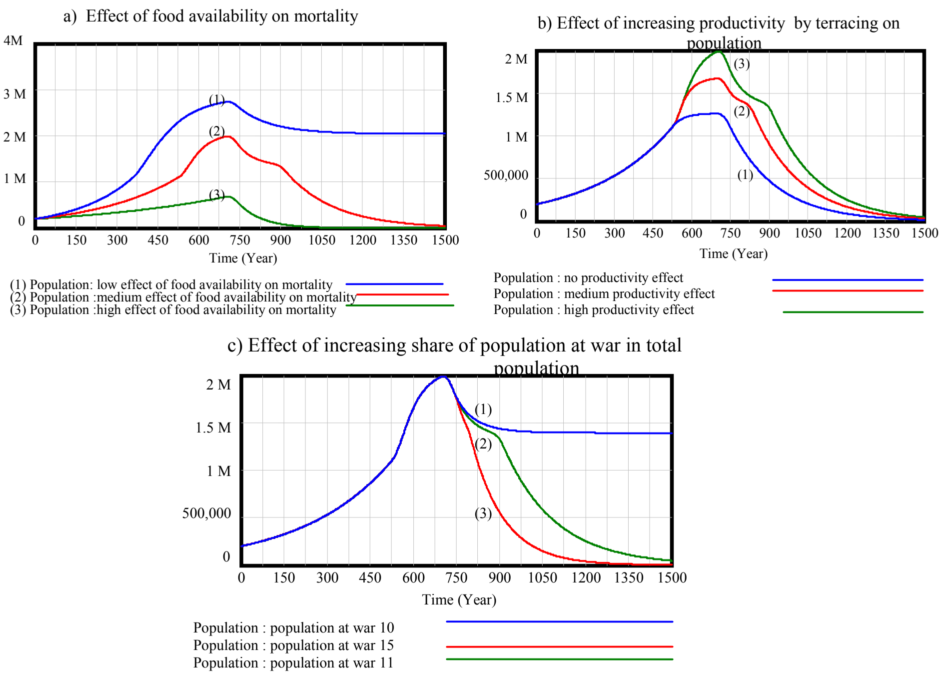
Figure 4 depicts the standard run of the simulation model presented in Figure 1.

Figure 4: Maya Population Dynamics – Standard Run



The three main assumptions for this run are: a) the annual mortality rate increases of 2.8% to 3.5% in the late classic period, following a lookup function as that shown in Figure 2; the occupation of slopelands starting in 500 AD increases the production of raising fields according the lookup function shown in Figure 3 and c) population involved in wars and monument building increases gradually from zero to 11% between 700 and 740 AD, reflecting the rise in conflicts among Maya kingdoms in the period. The conclusion is that the simulation seems to reproduce rather well the historical record of the collapse of the Maya civilization showing a sharp decline right after 750 AD and the virtual extinction of population by the first contact with Spanish conquerors. But it might be argued that this outcome would have been generated by a very particular choice of parameters. Thus it is worth to test the sensitivity of the above solution to variations in the range of the assumptions on mortality rate, effect of terrace production on productivity and the share of the population on war and monument building. Figure 5 presents the mains results of this analysis.

Figure 5: Sensitivity Analysis



a) Low effect: max mortality rate = 0.0312; Medium effect: max mortality rate = 0.0368; High effect: max mortality rate =0.0427; b) High effect: productivity in raising fields increase by 20% due to terracing ; Medium Effect: productivity increase by 10% and No Effect: productivity is held constant; c) Share of the population involved in wars and monument building varies from 10 to 15% of total population.

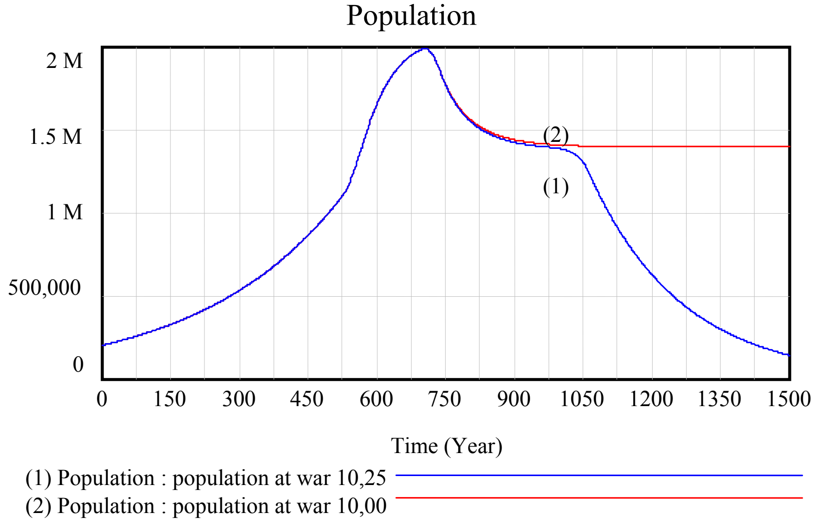
Assuming that is very likely that the share of population involved in wars and monument building has crossed the threshold of 11% (actually 10.25%, as we will see in next section), Maya society would have collapsed even though, terracing did not had any effect on the productivity in raising fields. That is, the main parameter to trigger the death spiral and hence to explain the collapse was the effect of food availability on mortality rate.

5 - Discussion

Out of simulations we might intuitively notice that the population collapse takes place because, at some point, the flow of births becomes smaller than the flow of deaths. A catastrophe like a big drought could certainly lead an entire society like the Maya to extinction. Adults who die will reduce the population level and thus the stream of future births. The death spiral could then be triggered by a sufficiently strong exogenous shock directly on any one link in the loop, for instance by a increase in the share of the population involved in wars and monument building due only to the effect of social circumscription (Carneiro, 1970). In this case, the greater involvement of the population in those activities would reduce food production, increasing mortality and thus reducing the future flow of births, which eventually would reduce the total population engaged in agriculture and the future availability of food. But what exactly is a strong enough shock?

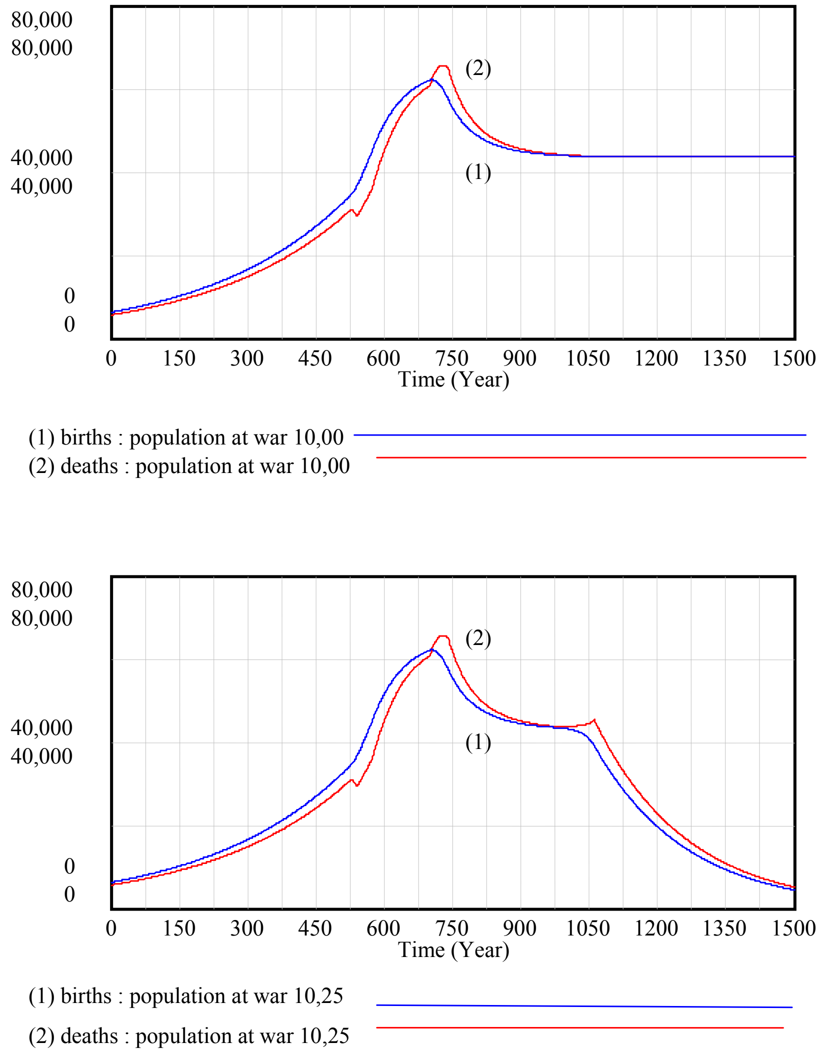
In Figure 6 we might see that the difference between sustainability and collapse can be very subtle. If the share of the population involved in wars and construction of monuments is at most 10%, society will be able to sustain its population level. But just crossing that threshold, say if 10.25% of the population becomes involved in these activities, might be sufficient to lead the society to a trajectory of collapse.

Figure 6: Share of the population in war, sustainability and collapse



The explanation for this somewhat counter-intuitive outcome is that if the population in war (pw) is at a maximum of 10%, decrease in production and food availability would lead to increased mortality, which will reduce to some extent the population. But the very fact that the population falls would reduce more the future flow of deaths than the flow of births, leading the population to a lower level, but not to collapse, as shown in the upper scenario of Figure 7. If pw is above this level, however, reducing the availability of food will lead the flow of mortality to be situated permanently above the flow of births as shown in the bottom scenario of Figure 7. By exceeding that level, the dynamics of the system would be driven by the death spiral positive feedback cycle, which would eventually lead to the extinction of the society.

Figure 7: Births and deaths in two scenarios for population in war



Resilience, again, may be seen through the lens of the bath tube dynamics metaphor. System is resilient while the birth flow is not lower than the death flow. People certainly can create institutions capable of preventing society to overshoot the carrying capacity of their environment, which, in the model, is the main factor to driven it to collapse. Yet, as the process of crossing system´s sustainability tipping point can be very subtle, people may not be aware that they are in a suicidal route. The experience that people have before crossing the tipping point on the contrary is likely to misguide them when the crisis arrive. After all, things went well before and apparently nothing really new has actually happened to suggest that they must change their behavior.

5 – Concluding remarks

Analyzing the growth experiences of a number of developing countries, Rodrik (2005) concludes that it seems easier to ignite than sustain growth. The main reason for this is that the latter requires a cumulative process of institution building to ensure that growth does not run out of fuel and that the economy remains resilient to shocks. The concept of resilience used by the author, though in a different context, is exactly the same discussed in this paper, namely the capacity of the economic system of not being trapped in collapse processes like the one we have labeled "the death spiral".

In the present paper we have attempted to show that growth processes is always driven by reinforcing positive loops. Maya population grew while environmental damage produced by increasing population was not strong enough to increase mortality rate beyond the fecundity rate. Mayas could have adopted institutional responses to increase productivity in agriculture hence checking increasing mortality rate and they indeed did that. But the very measures that worked in the short term contribute to aggravate the problem in the long term, leading their society to eventually overshoot the carrying capacity of the environment, which set the system to operate in the collapse mode of the reinforcing positive loop which, at first, leaded to population explosive growth and eventually to collapse. The problem in systemic terms is the same we find in all complex systems, that is they are capable to generate irrational social consequences in response to apparently rational human decisions.

Economic growth is one of such processes. To date, it is well established in the literature that a resilient economic process is one in which growth-spurring strategies are complemented overtime with a cumulative process of institution building capable of sustain a positive feedback loop of growth working in the right direction, that is in the opposite direction from the death spiral. In a classical paper, Engerman and Sokoloff (1993), suggested that it is plausible interpret the divergent growth trajectories of US and the Latin American former Spanish and Portuguese colonies in terms of positive reinforcing loops. The argument proceeds as follows.

The fundamental differences in factor endowments in the New World colonies, which were perpetuated by government policies, predisposed them toward different long-term paths. Unlike Latin American colonies, where factor endowments led to an extreme unequal distribution of wealth, human capital, and political power, United Sates (and Canada) was characterized since the beginning by relatively equality in all these dimensions. Greater equality in circumstances stimulated growth in US through encouraging the evolution of extensive networks of markets. This provided impetus to self-sustaining processes, that is processes driven by positive feedback loops, whereby expanding markets induced, and in turn are induced by more effective use of resources, the realization of scale economies, higher rates of inventive activities and other forms of human capital accumulation. This virtuous feedback loop, however, required a simultaneous operation of a coupled institutional positive loop in which the development of legal framework was conducive to private enterprise in both law and administration, which made the economic system more capable of sustain growth, that is made it more resilient. The development of an equalitarian patent system in US unlike in Brazil, for instance, was the most favorable in the world to common people at the time. This democratic institutional framework fed back to the first loop insofar technological innovations, which appeared largely as a cumulation of incremental improvements in agriculture and manufacturing which did not require extraordinary technical knowledge to discover and so was available to ordinary people to make, allowed access to broad markets. The greater their access to those markets, finally, the more productive and innovative individuals and enterprises were.

Traditional econometric tools are not particularly suited to deal with feedback loops or processes of circular causation. In his already classic paper on institutions and growth Daron Acemoglu et al (2001), for instance, have provided a very enlightening methodology for assessing the importance of the institutional framework for growth. Based on the fact that there is a clear endogeneity involved in the relationship between economic growth and institutions favorable to growth, they build a instrument for the variable institutions quality and, using the method of MQO in two stages, reach the conclusion that the mortality rate faced by colonizers was the more important factor to explain de differences in the future growth trajectories. Mortality rate was used as an instrument for institutions, because colonizers preferred bringing with them their families and institutions from the mother countries to low mortality regions. At first sight hence, countries' fate would be already determined by their early history, but it would be too deterministic. In other paper (2005), they propose a much more elaborated model of institutional evolution in which economic institutions co-evolve with political institutions according a difference equation system, which resembles the heuristic model proposed by Engerman and Sokoloff presented above, and in some ways the model we are proposing in this paper. Not surprising, since a system dynamics model is only a little bit more than a difference equation system presented in a friendly way. That is why we think the system dynamics approach might be a useful tool for complementing econometric and theoretical studies on economic growth.

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Appendix

Main Parameters

Maximum % of population in war and monument building = 0,20
Corn productivity in raising fields = 600 Kg per adult/year, amount enough to feed a family of two adults and three children per year plus 0.2 metric tons/year of corn (Flannery, 1976). Slopeland productivity was assumed as 50% of raising fields productivity (Denevan and Turner, 1985; Diamond 2005)
Average life span = 40 years
Base mortality rate = 1/average life span = 0,025
Fecundity rate = 2.5 children/woman or 0,0615 children/woman/year