A simple system dynamic model for the collapse of complex societies

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Abstract

This paper aims to show that incremental stress on environment can lead civilizations to overshoot their resource base as suggested, for instance, by Jared Diamond. Despite this author has recently been criticized by scholars from different areas, we think this criticism has likely been exaggerated. Diamond`s answers to the critics are actually not entirely convincing, because he has not a clear understanding of stock-flow dynamics. Hence, it seems likely that system dynamics reasoning might give more solid grounds to some of his insights under criticism. In this paper we intend specifically to show that societal collapses can occur even in the absence of extreme unexpected events, but just because the society has crossed a turning point beyond which traditional practices can become insufficient for dealing with environmental shocks like droughts. In order to accomplish this goal the paper builds a generic model for the Maya society based on the Rudolph and Reppening`s model for explaining the role the quantity of non-novel events play in precipitating disasters in organizations.

Keywords: system dynamics, Maya, societal collapses.

1 - Introduction

Previous works on the field have considered the loss of resilience[1] of social-ecological systems or even of entire civilizations mostly as a consequence of surprise driven crises that affect the systems' agents ability to cope with sudden perturbations (Carpenter *et al.*, 2001), such as extreme events of climate variation (Binford et al., 1997), unusually severe droughts (Weiss

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[1] that is the amount of disturbance a system can absorb without shifting into an alternate regime (Holling, 1973).

and Bradley, 2001), unexpected repeated episodes of droughts (Gill, 2000), sudden increases in resource extraction, e.g. in fishing (Jackson *et al.*, 2001), or environmental disturbances occurring in the conservation phase of social-ecological systems' adaptive cycles (Holling *et al.*, 1995). While work that has documented surprise-driven crises has been important in helping to develop an understanding of the dynamics of social-ecological systems, the role of piece-meal processes, that is the incremental effect of non-novel or routine factors may play in loss of resilience of organizations and social-ecological systems, has received comparatively less attention (Rudolph and Repenning, 2002). The main reason for this gap seems to be many people, including highly educated adults with substantial training in technology, engineering, mathematics and quantitative social sciences, as certainly is the case of many of the researchers specialized in studying societal collapses, have a poor understanding of stock and flows and the principles of accumulation (Sterman, 2010).

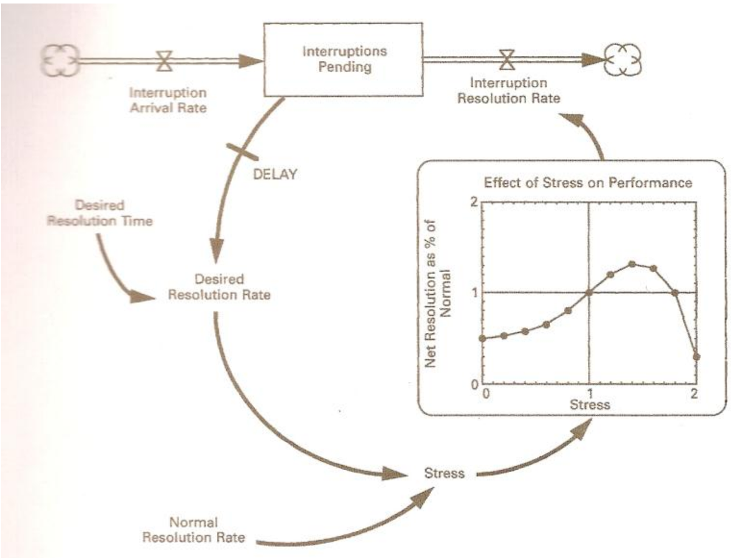
This paper aims at contributing to bridge that gap by showing that incremental stress on environment can lead civilizations to overshoot their resource base as suggested, for instance, by Jared Diamond (2005). Despite this author has recently been criticized by scholars from different areas, who find hard accepting that a society could watch its stock of natural resources fall year after year and do nothing about it (see for instance Page, 2005), we think this criticism has likely been exaggerated. Overshoot theories, for these critics, would deny the human capacity for flexible adjustments, including intensifying production (Tainter, 2006, p 72). Sophisticated people as the Maya, for example, certainly would have taken measures to prevent their civilization to collapse in response to the drought which took place in the end of Late Classic period, mainly keeping in mind they had survived droughts over 3500 years up to this point. In particular, it seems hard to explain why should resource stress lead to collapse is some instances and economic intensification in others? Diamond`s answer to this questioning is actually not entirely convincing, likely because he himself has not a clear understanding of stock-flow dynamics. Hence, it seems likely system dynamics reasoning might give more solid grounds to some of his insights under criticism. In this paper we intend to show, specifically, that societal collapses can occur even in in the absence of extreme unexpected events but just because the society has crossed a turning point beyond which traditional practices can become insufficient for dealing with environmental shocks like droughts.

The paper is structured as follows. Section 2 presents two examples of societal collapses sketching a generic systemic model for explaining those processes in ancient societies based on the Rudolph and Reppening`s model for explaining the role the quantity of non-novel events play in precipitating disasters in organizations. Section 3 presents a generic model for the Maya society based on the Rudolph and Reppening`s model and section 4 displays the most relevant results. Section 5 discusses the results showing how collapses may be seem as piece-meal processes in which people may be unable to identify the signs of the disasters before it is late. Section 6 concludes the paper.

2 – Great societal collapses: the reference mode

One of the most influent explanation of societal collapses posits that a society has collapsed when it displays a rapid and significant loss of complexity (Tainter, 1988, p. 4), manifested in such things like a lower degree of stratification and social differentiation, less investment in monumental architeture and artistic and literary achievements, smaller territory a population integrated within a single political unity, and the like. The shift to increasing complexity which takes place in the phase of expansion, on the other hand, is undertaken to relieve stress or realize oportunities yielding a favorable marginal return. Continued stress and increasing costs of sociopolitical integration combine to lower the marginal return turning societies progressively more vulnerable to stress surges which eventually makes collapse increasing likely. This interpretation is essentially the same as the system thinkers have given to the process of collapse of organizations. One of the most interesting of those explanations is given by Rudolph and Repenning (2002) synthesized in figure 1.

Figure 1: A model for organizational collapse



Source: Rudolph and Repenning (2002)

They assume that organizations face a continual stream of non-novel interruptions in their ordinary activities. The stream of incoming interruptions accumulate in the stock of *interuptions pending*, which is reduced by the outflow *interruption resolution rate*. As the number of interruptions rise the desired resolution rate also rises. Stress is modeled as arising from a mismatch between the desired resolution rate and the rate at wich interruptions are normally resolved. To capture the linkage between the stock of unresolved interruptions and performance the authors draw on the Yerkes-Dodson law, which posits and inverted U-shaped relationship between stress and performance on moderate to difficult tasks. The dynamics of the system is quite different depending on the portion of the Yerkes-Dodson curve it is. In particular, if the stress level rises enough to push the system into the downward-sloping portion of the curve, the added stress causes a decline in the resolution rate, that is the dynamics of stress and performance do not perform a regulatory function (as occur into the upward portion of the curve) but rather amplify changes in stress in a reinforcing feedback process. Experiments with the model suggest that systems like the one presented above have thresholds of accumulation beyond which their response to new demands fundamentally changes. Whereas when they operate below those thresholds they are resilient, in the sense they are capable to accommodate changes in the number of incoming interruptions, once those thresholds are crossed, performance rapidly collapses. Beyond those (tipping) points the system dynamics is driven by a donward spiral which leads the system to collapse even in the absence of new interruptions. It is surprising how well this model appears to fit the Tainter`s explanation for the collapse of two great civilizations: the Roman empire and the Maya society.

While the factors which led to the Roman expansion in the last few centuries B.C are subject to speculation, it is undeniable that the policy was at first highly successful, but, due to the rising costs of maintaining the new areas conquered, that expansion fell off in the first century AD. From Nero, in 64 AD, emperors began to debase currency which was clearly inflationary and brought dissatisfaction for large sectors of the population. Bands of military deserters plagued parts of the empire and around the middle of third century order was beginning to break down. The half century from 235 to 284 AD was a period of unparalled crisis during which the Roman Empire nearly came to an end. The situation was rescued by Aurelian in 270-5 AD, wich pushed back the barabarians, reformed the coinage and reattached rebellious provinces. The Empire that emerged under the next rulers was administred by a larger, more complex and more organized government which commanded larger and more powerful military forces. In order to assure its survival, it taxed citizens more heavily, conscripted their labor, and regulated their lives and occupations, becoming a coercive and omnipresent state. The changes instituted made the Empire more efficient and better defended, but a high costs. Those costs had to be supported by a depleted population which never had managed to recover from the plagues of the second and third centuries.The consequence of this for the Empire was a decline in personel for agriculture, industrial, and military and civil services. The decline in agricultural labor, particularly, led to a significant abandonment of arable, and formely cultivated, land, because under these conditions the cultivation of marginal land became unprofitable due to the high taxes levied by State. The Empire survived the third century crisis therefore, but a cost that weakened its capacity to face future crises. Like in the disaster in organizations model presented above, response to stress changed when the system crossed its tipping point: initially, as stress increased, performance also increased; eventually, however, increases in stress caused a decline in performance. Once this threshold was crosssed "… a downward spiral ensued: reduced finances weakened military defense; while military disasters in turn meant further loss of producing lands and population. Collapse was in the end inevitable, as indeed it had always been." (Tainter, op. cit. p. 150).

The second example studyied by Tainter was the collapse of Maya civilization in the Southern Lowlands. After a period of intense population growth in the Middle and Late

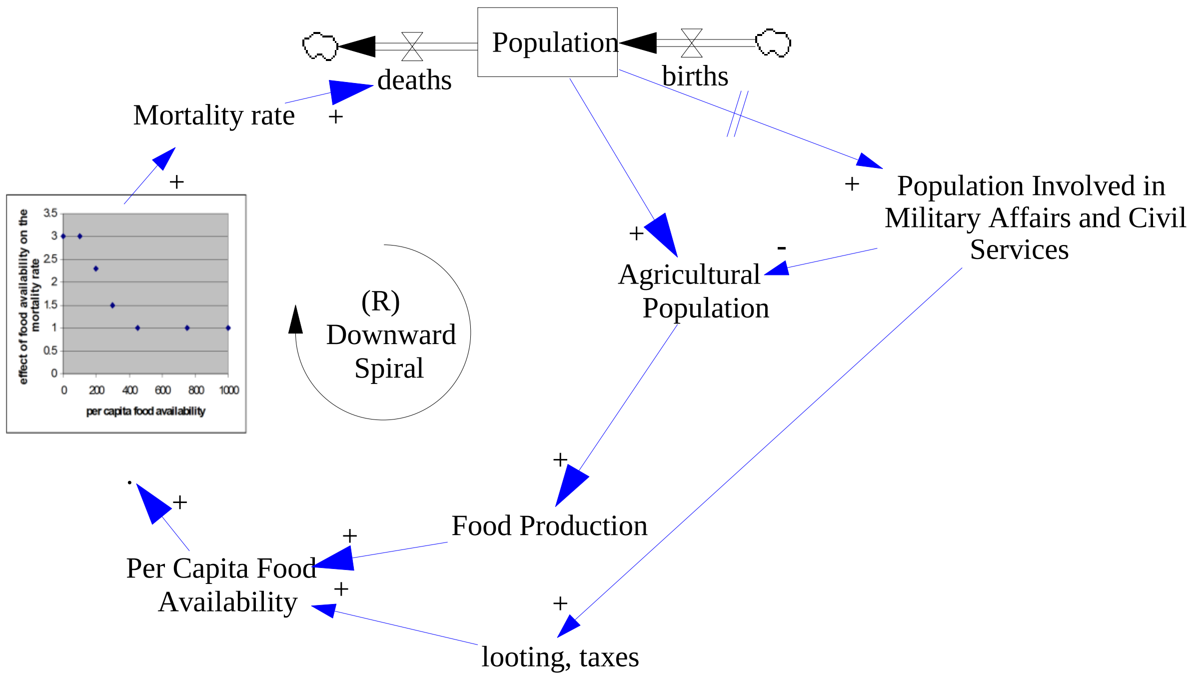
Preclassic ages, which indicates that farmers were highly successful in developing creative solutions to increase agricultural productivity, food production began to levelling off and military competition among the kingdoms began to spread intensifying in the Late Classic, that is between 600-800 AD, right before the collapse in various localities. The fact that Maya collapse was preceded in many centers by a burst of monumental construction, as noted by the most influent Mayanists, was not an accident. Given the costs of wars, the best streategy for any Maya polity, once the situation had stabilized, was deterrence. Without large permanent armies, monumental architecture, painting (of horrible treatment to enemies), and sculptural art was an efficient way to communicate the relative strenght of political centers. By engaging in architetural display, a center could signal to potential competitors the relative population numbers that it could mobilize. The Maya in the classic period, therefore, were engaged in a system of competitive relation in which advantage would accrue to the centers that were larger, that invested more in competitive display, and that could mobilize greater populations. High population densities, on the other hand, pressuposed vast hydraulic and agricultural engineering and considerable sociopolitical complexity Yet, Late Preclassic population were clearly under stress due to shortage of food. Both infectious aand nutritional diseases were prevalent in larger centers like Copan and the average age at death of city dwellers declined in the Late Classic.

The factors that led to the Maya collapse –in Tainter`s words – can then be synthesized ina a theoretical framework as follows:

> "The stresses and pressures of the Preclassic and Classic periods set in motion a dynamic, interlinked system of competition and warfare, support of an elite hierarchy, investment in monumental construction, hydraulic and agricultural engineering, and administration of growing regional domains. The costs of supporting this system fell entirelly on the agricultural support population. To be sure, this growing investment in complexity must have had benefits, for a strategy pursued for 1200 years or more, and intensified through time, cannot have been entirelly unsuccessful. Yet it is also clear that the marginal return on this investment deteriorated over time. Ever increasing investments in warfare, complexity, monumental construction, and agricultural intensification yield no proportionately increasing returns in the health and nutritional status of the populace. To the contrary, as demands on the support poopulation increased the benefits accruing to that population actually declined." (p. 175)

Diagram in figure 2 synthesizes the collapse dynamics we have just presented.

Figure 2: The basic stock and flow structure for the collapse of ancient societies



In both examples above, the societies had long periods of expansion in which, thanks to the development of institutional and technological solutions for the problems of accommodating growing populations in resource-constrained environments, food production accompanied or even outpaced population growth. As the per capita availability of food did not decrease, the mortality rate of the population did not increase. The graph on the left side in figure 2 posits that while per capita annual availability of food (e.g. grain) does not fall below 400 kg, the mortality rate will be multiplied by 1. When it falls below that level, on the other hand, the mortality rate is multiplied by a number larger than one; for instance, if food availability drops to around 200 kg, annual mortality rate will be multiplied by 1.5. While the mortality rate is lower than the fertility rate, the population increases, which, at some point, will make profitable engaging larger portions of the population in military affairs to conquer new territories and appropriate of foreign resources though taxes or looting. The territorial expansion, however, exhibits diminishing returns, at least beyond a certain point, forcing a gradual allocation of agricultural workers to military purposes (including the construction of monuments as in the case of the Maya). In predominantly agricultural societies, the allocation of workers to non-agricultural activities eventually leads to a reduction in the production and availability of food, which at some point will lead to an increase in the mortality rate. When, finally, the mortality rate rises above the fertility rate the system enters a downward spiral of population reduction, which is the most obvious manifestation of societal collapse. The question that arises is: why the increased mortality leads to a collapse and not to a mere adjustment of the population dynamics, with a slower rate of growth, or even to a stabilization at a lower level? The explanation is that crossing of a tipping point is generally a very subtle process, which contemporaries might find hard to detect. And even in the unlikely event that they did, these are times when traditional practices are no longer effective to prevent societies are trapped in downward spirals of population loss. In next section, we provide quantitative evidence for these propositions, based on simulations of a simple model for the dynamics of Maya civilization.

3- Testing the model: The Maya collapse

3.1 – a short description of the Maya society and economy

According 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 only 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 the following

Maya economy was essentially a human-powdered one. This feature, on the one hand, explains the relatively low productivity it presented even though its agriculture had been able to introduce a number of techniques such as terracing of hill slopes and arrays 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, combined to the redundancy of the resource zones along the landscape, which discouraged economic cooperation and trade among Maya centers, explain why Maya society remained politically divided among small kingdoms constantly at war with each other (Webster, 2000, p. 71).

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, was already mentioned, 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 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[2]. 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.

As population grew, 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

[2] Some authors even believe that, thanks the introduction of those techniques, it is impossible to be sure that the Maya agricultural system had indeed reached its productive limits and therefore doubt reduced productivity caused the civilization collapse; see for instance Rice and Rice, 1984. That, however, is a minority position in the more recent literature.

> forest regrowth. It may consequently have taken 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 (Tainter, op. cit. p. 174).

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[3]. When the death spiral started to dominate the system dynamics the collapse was rapid and inevitable. Figure 3 below illustrates the whole process.

3.2 – The model

Figure 3 in the next page depicts the simplified stock-flow structure of the complete systemic dynamics model used in the simulations made in the next section[4]. 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:

[3] This downward spiral is an archetypical trap known by system thinkers as accidental adversaries or escalation. See for instance Senge et al. , 1994, pp. 145-148.

[4] A more detailed presentation of the model is given in Pacheco et al., 2010; the complete VENSIM model is available upon request to the authors.

$$\frac{d\,Population}{dt} = births - deaths$$
$$births = Population \,.\times \%\, females \,.\times\ fecundity\ \ rate$$
$$deaths = Population \times mortality\ \ rate$$

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 fertility rate is 0,0625, considering an average 40 years life span in Maya sites (fertility 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:

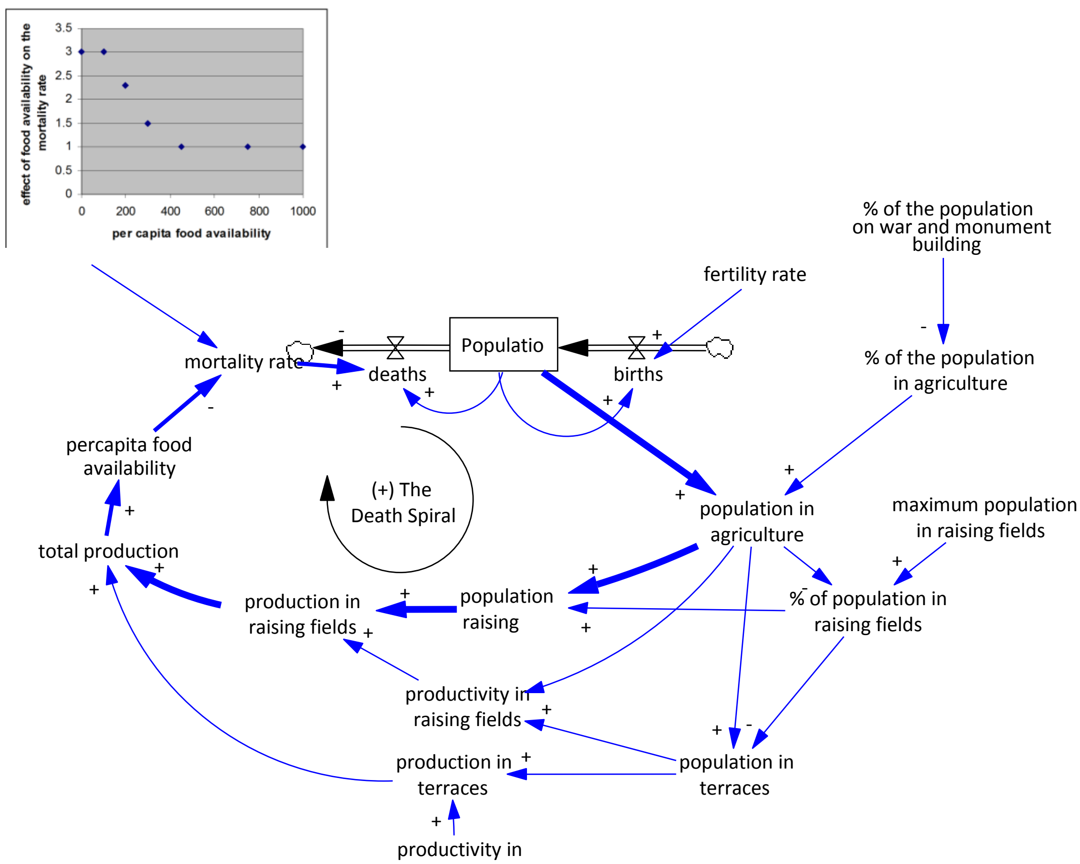
mortality rate = effect of food availability on mortality (per capita food availability)*base mortality rate

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))

Figure 3: A simple model for the Maya collapse



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, reaching the maximum of 20% of total population in the last year.

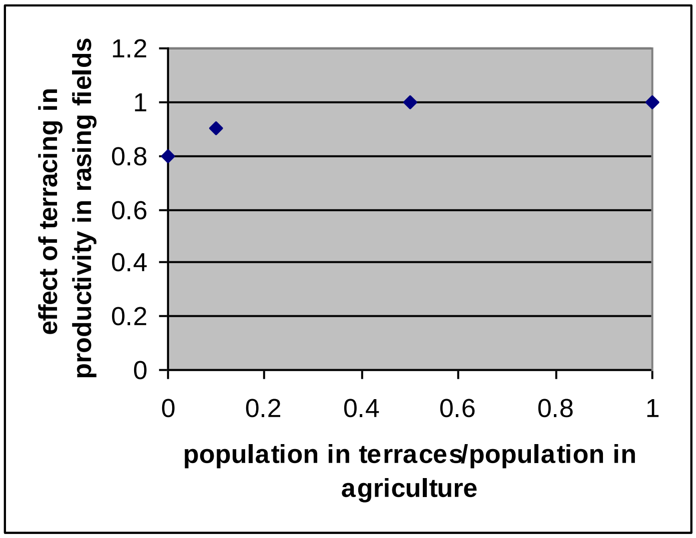
The effect of the decrease of population in the productivity in raising fields is modeled as:

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 4.:

Figure 4: The effect of terrace production on the productivity in raising fields

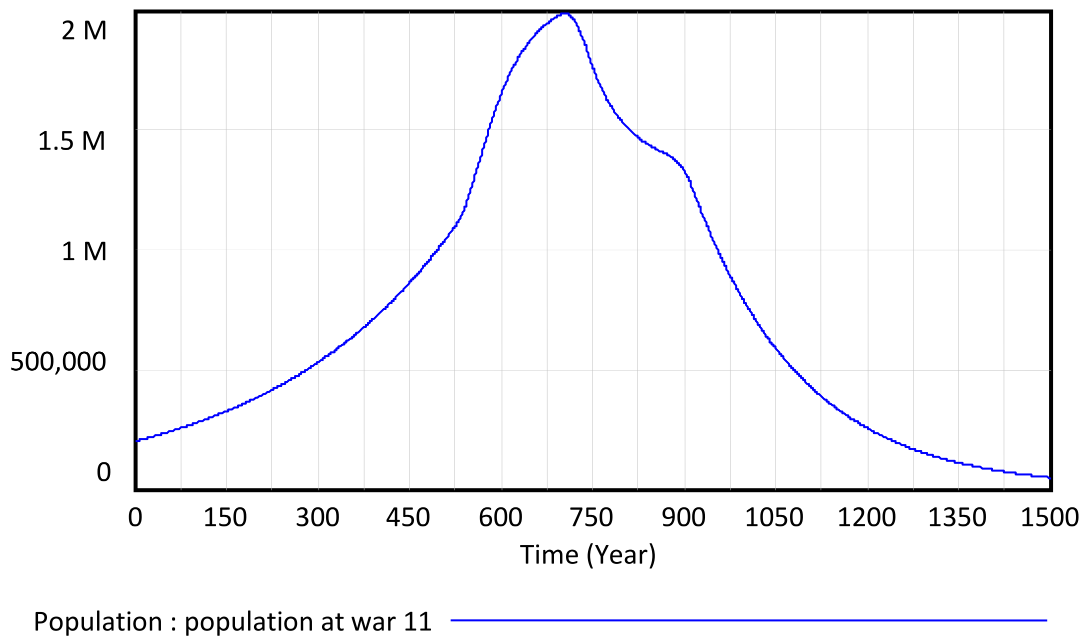


The basic dynamics of the model is as follows. Population growth leads to increasing food production at a constant per capita rate. When terraces begin to be used, average production decreases since productivity there is lower. This make war to conquer more fertile territories a more attractive strategy and thus more people are allocated to military affairs. But, then, food production fall which leads to a higher mortality rate. 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 takes place decreasing productivity in raising fields and per capita food availability. The downward loop labeled 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

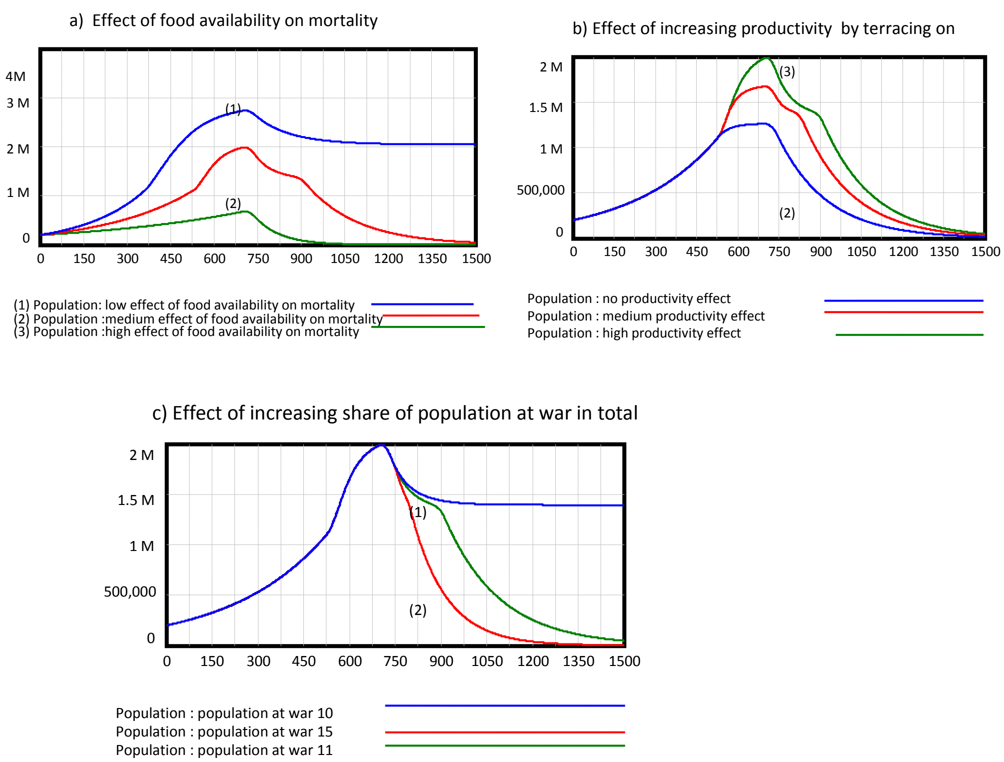
Figure 5 depicts the standard run of the simulation model presented in Figure 1.

Figure 5: 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; the occupation of slopelands starting in 500 AD increases the production of raising fields according the lookup function shown in Figure 4 and c) population involved in military affairs 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 quite well the historical record of the collapse of the Maya civilization. A sharp decline 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 6 presents the mains results of that analysis.

Figure 6: 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.

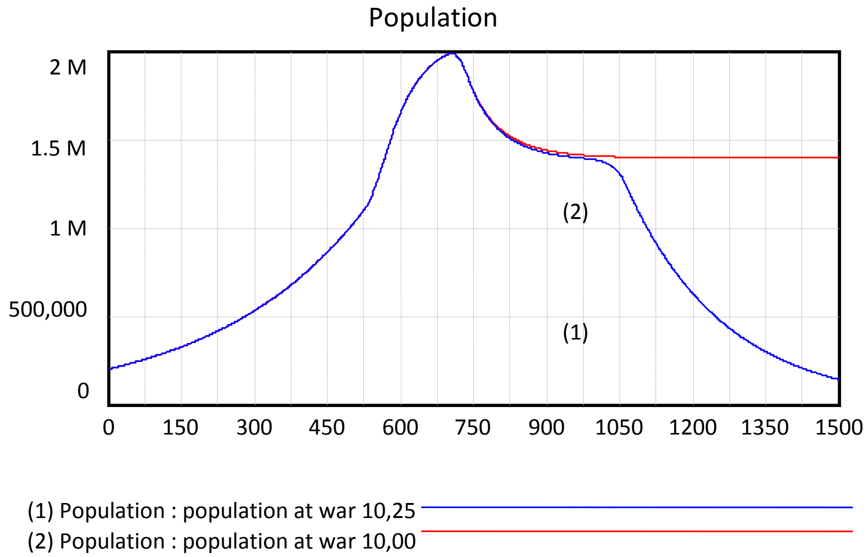
Assuming that is very likely that population involved in wars and monument building has crossed the threshold of 11% (actually 10.25%, as we will see in next section), Maya society would have collapsed even though terracing , while playing an obvious role in shaping the actual collapse trajectory, had 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 might 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 can then be triggered by a sufficiently strong exogenous shock directly on any one link in the loop, for instance by an 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?

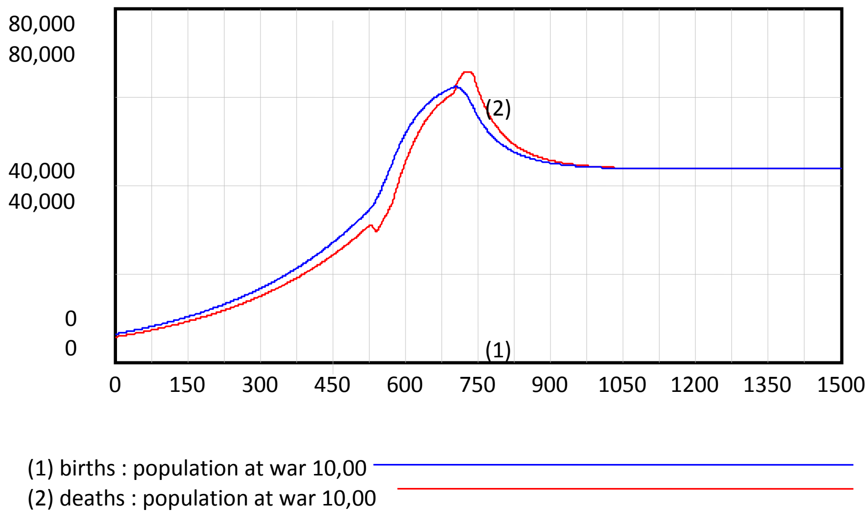
In Figure 7 we see that the difference between sustainability and collapse can be very subtle. If the share of the population involved in wars and construction of monuments is at most 10%, society will be able to sustain its population level. But just by crossing that threshold, say if 10.25% of the population became involved in these activities, society would have entered a collapse path.

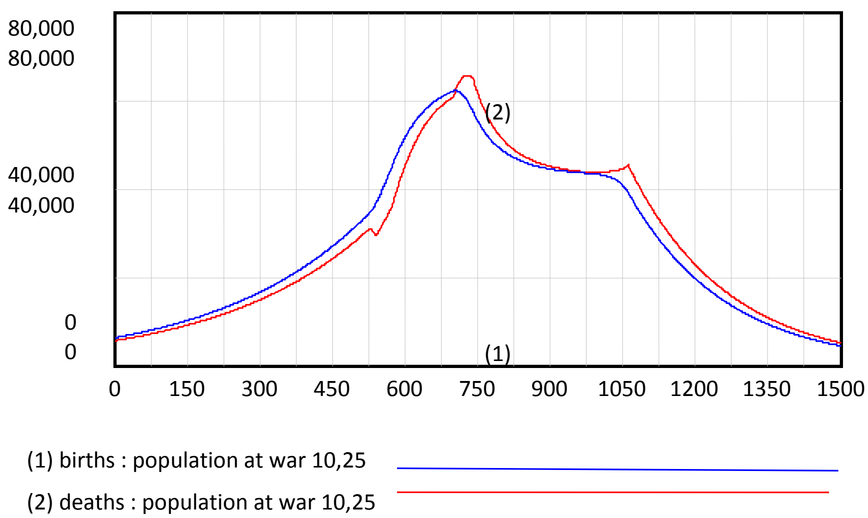
Figure 7: Share of the population in war, sustainability and collapse



Why is that? The explanation is that if the population in war (pw) is at a maximum 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 8. 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 8: Births and deaths in two scenarios for population in war





6 - Conclusion

Is the model discussed in this paper sufficient for explaining all collapses that occurred in human history? Of course not. The varied natural (seasonality, local resources) landscapes, different subsistence technologies and settlement patterns and the like certainly result in a multitude of political stories about how societies arose and collapsed. Yet, we do not agree with some authors who find useless attempting to build a generic model for those processes[5]. To the contrary, we have attempted to show that system dynamics can help to highlight common features of societal collapses that have not been emphasized by traditional studies in the field. The main insight provided by this methodology is that an incremental effect may be a major cause of loss of resilience of societies like the Maya civilization. As organizations, societies facing an ongoing stream of routine stressors have thresholds or tipping points beyond which performance rapidly collapses. We showed that that happens because at those thresholds changes in looping dominance occur. For lower intensities of stress, balancing loops tend to lead the system to an equilibrium state. For higher levels of stress, the system may be pushed away from the equilibrium and reinforcing loops begin to dominate the system's dynamics. People certainly can create institutions capable of preventing society to overshoot carrying capacity of their environment. More often than not, however, they do not recognize that their systems are falling into a collapse trajectory (Moxnes, 2000). The experience that people have before crossing the tipping point is likely to misguide them when the crisis arrives. After all, things went well before and apparently nothing new has actually happened to suggest they must change their behavior. Nevertheless, perhaps the understanding that small changes may in certain circumstances lead to drastic changes on the environment may help us to better understand the dynamics and build preventive measures with which we can maintain our social-ecological systems.

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[5]Lucero, 1999, p.244, for instance, thinks to be not possible to apply one model to analyze the collapse of all Maya sites due to the fact that varied natural and social landscapes resulted in a multitude of political histories throughout the lowlands .

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