In this modelling section, we are going to model the decline of the Maya civilization, based on a relatively old and simple model published last century:

One of the great mysteries of human history has been the sudden collapse –around 800 AD– of one of the main centers of Mayan civilization in Central America at a time when it was apparently peaking in terms of culture, architecture and population. No one knows exactly why this society of several million people collapsed, but new research shows a gradually tightening squeeze between population and environment that may have been crucial to the fall. Tropical environments are notoriously fragile.

Scientists of Florida State University and the University of Chicago estimate that there was an exponential growth in Mayan population during at least 1700 years in the tropical lowlands of what is now Guatemala such that the population doubled every 408 years. This trend may have caught the Maya in a strange trap. Their numbers grew at a steadily increasing pace, but, for many centuries, the growth was too slow for any single generation to see what was happening. Over the centuries, the increasing pressure on the environment may have become impossible to sustain. Yet the squeeze could have been imperceptible until the final population explosion, just before the collapse. New estimates for the southern lowlands are based largely on a detailed survey of traces of residential structures that were built, occupied and abandoned over the centuries. The studies focus on the region of two adjacent lakes (Lake Yaxha and Lake Sacnab) in the Peten lake district of northern Guatemala. The area was inhabited as early as 3000 years ago and the first agricultural settlements appeared there about 1000 BC. The land was largely deforested by 250 AD. Gradually-intensified agriculture and increasing settlements seem to have caused severe cumulative damage to an originally verdant environment. Essential nutrients washed away in the lakes, diminishing the fertility of agricultural land. Increases in phosphorus in the lakes from agriculture and human wastes seem to have aggravated the environmental damage.

Model Construction

The following will provide you with an outline to construct the model. Note that there are **4** stocks.

Through a process of *deforestation*, the Mayans transformed *Forest* into *Agricultural Land*. This rate was dependent on closing the *Gap* between the *Food Produced* and *Food Demand*, given the *Fertility of Agricultural Land* according to:

Deforestation = MIN(Gap / MAX(Fertility of Agricultural Land, 1), Forest/4) / Intensity

Where *Intensity* refers to the intensity of agricultural activities, which equals 1 in our base model. At such an intensity, all the required forest to be transformed is deforested within a year.

The *Population* grows through *Births* and decreases through *Emigration*. The latter is equal to the *Gap* divided by *Food Consumed per Person*, multiplied with the *Emigration Ratio*. This *Emigration Ratio* is equal to 5% and represents the people that emigrate due to food shortage, while the rest of the population redistributes the existing food. The *Birth Rate Coefficient*, which regulates the inflow of the *Population* will have to be found using the fact that the population doubled every 408 years. If you cannot find this value, use 0.0018 (be aware the timings in your model will then differ)

Initially, the *Fertility of Agricultural Land* is equal to 5000000 kg/(km2*year) and can decrease through *Fertility Losses*. This rate of *Fertility Losses* equals Fertility of Agricultural Land*MIN(2,(Agricultural Land/Forest)^1.9)/Intensity. Basically, this rate is proportional to the already existing fertility and multiplied with a "quadratic relationship" between the Agricultural Land and Forest. The value 1.9 ensures we obtain a collapse around 800 AD, as indicated in the text.

The *Fertility of Agricultural Land* allows us to compute the *Food Produced* if we multiply it with the *Agricultural Land*.

It's estimated that the initial *Forest* was around 5000 km2 and the initial *Agricultural Land* approximately 8km2

The *Gap* is simply the *Food Demand* minus the *Food Produced*. The *Food Demand* depends on the *Population* and *Food Consumed per Person*. The *Food Consumed per Person* is roughly 400 kg per person per year.

1. Construct the model in Vensim (40 points)
2. Find the *Birth Rate Coefficient* as explained in the text. Also set the simulation time parameters such that the timings are correct. (10 points)
3. What's the behaviour mode called that we observe in the model? How did this happen? Make sure you ground the explanation in the model structure and historical context as given in the text. (15 points)

4. How sensitive is the model to changes in certain parameters? Briefly explain (10 points)

5. What would you change or add to the model to better represent the processes described in the text? As a starting point: look at the processes that the model represents and how they've been simplified. Take care in identifying the first set of improvements without resorting to completely new sectors that aren't directly relevant. For instance, adding economic sectors may not be that relevant in this case. (10 points)

6. Which other systems are, or could be, similar to the one that's been studied here? Explain. (5 points)

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7. Which policy or policies could have prevented the collapse of the Maya civilization? Give a suggestion and implement it in the model (recall that closed loop policies may be more effective, if you can find one). Points are only rewarded if a policy suggestion is implemented in the model. (10 points)

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