Modeling Cases from Jared Diamond's “Collapse”

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Abstract:

Throughout history some societies, including the Maya, Anazi and Easter Island, have collapsed, while others facing similar challenges, such as New Guinea and Japan, have succeeded. The Maya and New Guinea cases were taken from Jared Diamond's study, "Collapse," to create a system dynamics model capable of producing both the collapse and success behavior. The endogenous pressures described by Diamond were used to develop the feedback story. Policy interventions undertaken in by the society in the model were controlling family size, increasing farming intensity, reducing resource usage and composting. In the initial attempt the society enacted these interventions in response the cues of food shortages, perceived environmental degradation and falling crop yields (an indicator of soil quality). However, using this set of cues the society was incapable of creating the success behavior mode, ruling out these cues as ones successful societies could have used. In the second scenario, the society used a target land fraction occupied as its main cue and the gap between needed food production per acre and actual food production per acre as the drive to increase composting. This cue set was able to produce success behavior, which establishes these cues as possible cues a successful society could have used.

Keywords: system dynamics, complex society collapse

Background

Jared Diamond explored the causes of collapse or success of societies in his book, Collapse, in which he focuses on a series of case studies. He makes the overarching argument that it is the choices a society makes, which determines whether it succeeds or fails rather than external circumstances.

If this is the case, then a single model based on his descriptions of past societies (both successful and not) ought to be able to produce both the collapse and success behaviors. The goal of this project is to produce such a model.

From the sum of the case studies, Diamond identified five contributed factors to the success or collapse of societies: environmental damage, climate change, hostile neighbors, loss of important trade partner, and response to problems.[1]

Of these, he asserts that the first four may or may not all be significant in an individual case, but that response to the societies problems always is. In evaluating these factors for inclusion in the model, first whether they were part of an endogenous feedback story or an exogenous factor was considered. Based on this, climate change was eliminated as being a purely exogenous factor.

Second, attention was given to the applicability of each factor to two chosen case studies, Maya and New Guinea. Neither Maya nor New Guinea had important trade partners so this factor was eliminated from the model. In contrast both Maya and New Guinea experienced constant states of warfare. However, because they had this in

1 Many previous studies have provided excellent examinations of overshoot and collapse, including Limits to Growth: the 30-Year Update by Donella Meadows, Jorden Randers, Dennis Meadows, 2004 and Generic Structures: Overshoot and Collapse by Lucia Breierova, 1997. However, for the purpose of this model only Diamond's descriptions were used in order to better test his description of societal decisions being the deciding factor within the context he used.

common, it is not likely to be an important determinant of their success or failure. In this way, the major factors were reduced to environmental damage and response to problems.

Reference Modes

Based on these case studies, four reference modes were developed. Such reference modes show the historic behavior over time of an important variable in the problem as described by Diamond. These graphs form a basis against which to compare the results of the model and evaluate its ability to replicate historical behavior. All reference modes for this model have two behavior modes: one representing the variable's behavior when the society is successful and one representing the variable's behavior when the society collapses.

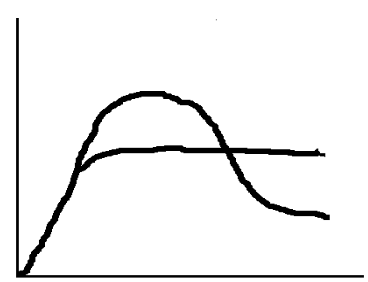


Figure 1: Population Reference Mode

The first reference mode shows the behavior of population over time. In the collapse case, the population grow exponentially until it reaches a peak. Then the population collapses, meaning that it decays exponentially to at or below its starting point. In the success case, the population again grows exponentially to a peak. However, at it levels off to a steady, sustainable value instead of collapses. Such a value will be lower than the peak of the collapse case. This is because the failed society peaked above the sustainable level.

The second reference mode is natural resources. In the collapse case, natural resources are depleted below the sustainable level and remain low as the population collapses. In the success case, natural resources follow the same behavior mode as in collapse, but are not depleted as severely. Either because the population does not grow as large, they make efforts to reduce resource use, or otherwise take corrective action, the natural resource situation is not allowed to get so dire. It is also possible that in the success case, resources will begin to recover during the run, depending on the policies the society implements.

Figure 2: Natural Resource Reference Mode

The final reference mode was the soil quality reference mode. In the collapse case, the soil quality was depleted resulting in reduced agricultural productivity. In the success case,however, the society was able to compensate for the falling soil quality through composting and other efforts.

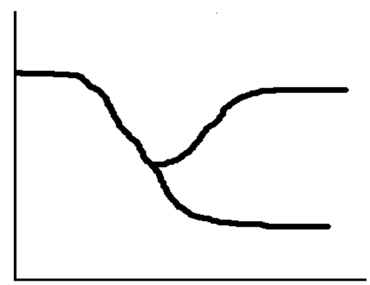


Figure 3: Soil Quality Reference Mode

Feedback Loops

Six primary feedback loops contribute to collapse.

1. (R) Population Growth
2. (B) Food Constraint
3. (B) Crowding
4. (R) Farming Intensity
5. (B) Farming Labor Shortages
6. (R) Natural Resource Capacity Erosion

(R) Population growth is the natural tendency of the population for exponential growth. This comes because a higher population means more births, while more births in turn means a higher population. Population continues to grow until constrained by a limited food supply. As food per capita declines the average life expectancy also declines. A lower average life expectancy means that the population will be lower than it would otherwise have been.

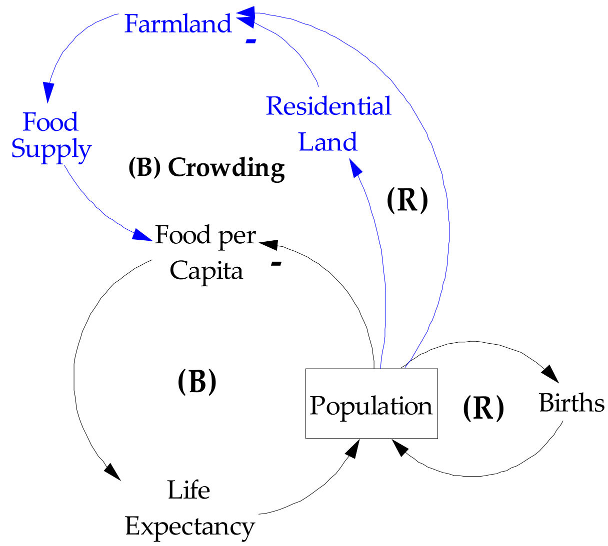
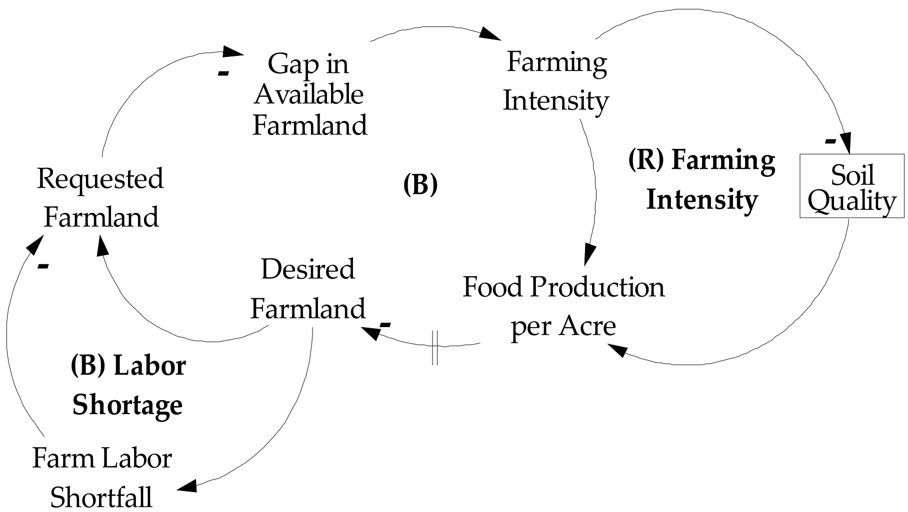


Figure 4: Population Growth, Food Constraint and Crowding Feedback Loops

Such lower food per capita is a result of the (B) Crowding loop, shown above the other two. As population grows, residential and farmland take up ever greater amounts of the total available land. Once the land is used, the farmland is no longer able to expand sufficiently to meet the food needs of the population, making food supply lower than it would otherwise have been.

To combat these effects, the society will try to farm the land that is available more intensely. This is represented by the (R) Farming Intensity loop. Unfortunately, the intensified farming practices have the side effect of depleting soil quality. Lower soil quality means food production will be lower than it would otherwise have been. This in turn spurs farming intensity to compensate.

The push for more farmland and greater intensity can eventually be limited through the balancing loop (B) Farm Labor Shortage. If soil quality is low enough, it may take more farmland to grow enough food then the available farmers can manage. In this case, less farm land will be requested and allocated.



The full model is included in the supplemental materials and can be referred to for the full structure and implementation of these loops.

Parametrization

The models were given generic parameters based on Diamond's descriptions of the two societies because the model is meant to represent both. The parameters are to scale with both the Maya and New Guinea case and sensitivity testing was conducted on the parameters. The sensitivity tests showed no impact on the behavior modes of the model.

Model Results

When the society made no efforts to avert catastrophe and the result is a sudden sharp collapse. Figure 5 shows this dramatic drop in population, along with a fall in food per capita and the depletion of natural resources. Figure 6 shows the effects of the erosion of carrying capacity described in the reference modes. It can be seen that food supply peaks years before the total farmland area peaks. This is because the falling soil quality reduces the productivity of each acre to the point where increasing farmland cannot compensate. Farmland begins to decrease after population peaks, both because demand for food drops and because there are no longer enough laborers to maintain that level of farming.

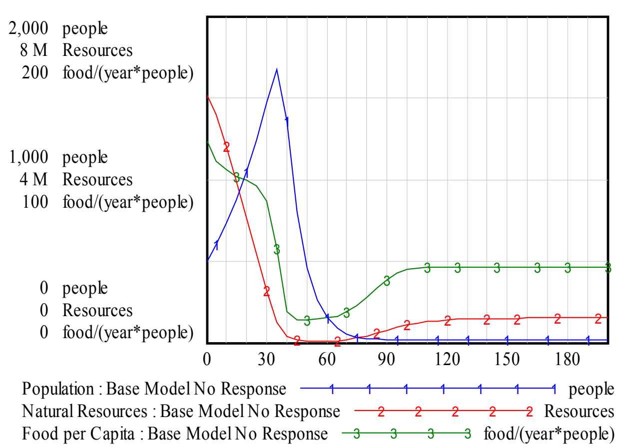


Figure 5: Base Model Main Variables

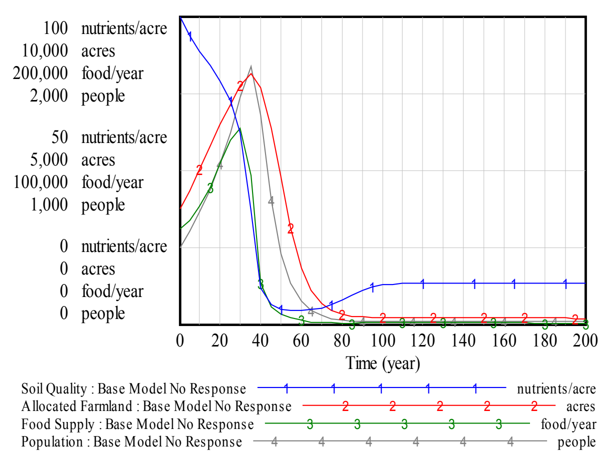


Figure 6: Base Model Run Crop Production Variables

Next, several intervention scenarios were tested to see if they would allow the society to divert this catastrophe.

Interventions

Three interventions were included in the model. The first is a population control measure. This represents the society controlling the birth rate, through family size, to slow, halt, or in the extreme reverse, the trend of population growth. The second intervention was the addition of composting. This would allow the society to compost and improve soil quality. The final intervention was a reduction in desired resource usage per person. This would result in the society wanting to use fewer natural resources per citizens.

Next it had to be established, when the society would utilize these interventions, or what cues they would use to perceive a problem that needed to be addressed. To do this, two separate cue sets were used and tested. For both sets the interventions were held constant and other parameters were subject to extensive sensitivity testing.

Cue Set One

In considering what cues to use, two criteria were considered: the cues must be observable by a society with low technology levels and must be linked to a problem. Three cues were chosen for this initial attempt at sustainability. The first cue was food shortages because the society would natural become alarmed at any serious food shortage. Food shortage was calculated a percentage of the actual food per capita over the desired food per capita.

The second cue was perceived environmental degradation. This cue recognizes that people may change that people may change their behavior in response to damage they see in their environment. This effect, however, is mitigated by a perception delay. That is, people remember what the land looked like twenty or sixty years ago but not one hundred years ago, the effect Diamond referred to as “landscape amensia”. This can result in an eroded standard for environmental quality. Additionally, if natural resources decline to a trivial amount, this cue is phased out in favor of the other two cues. This reflects that a society will shift its economy away from these resources if they are gone and they will become less important over time.

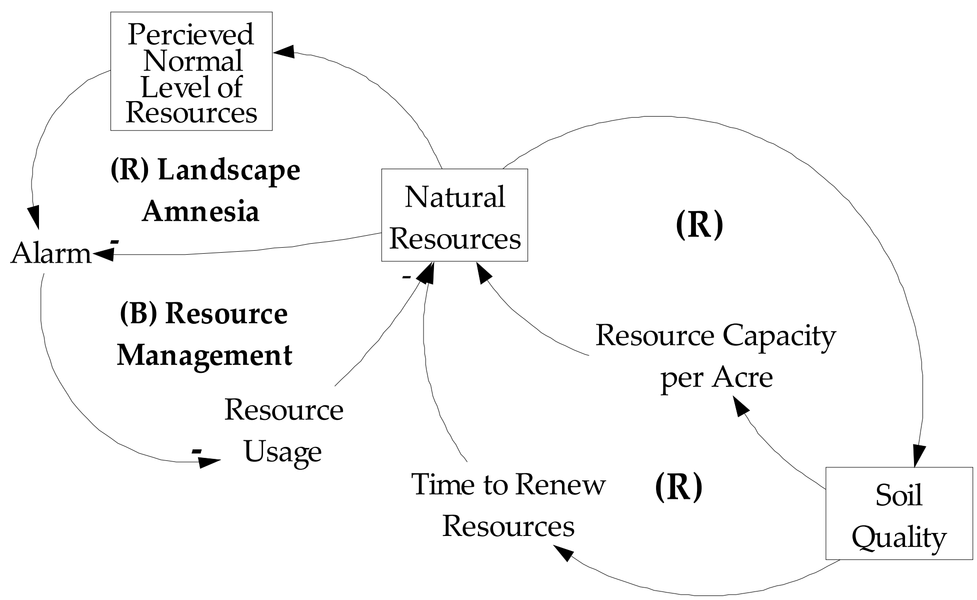


Figure 7: Landscape Amnesia Effect

The final cue was a perceived decline in soil quality. This was used as an easily observable indicator of soil quality. If food production falls

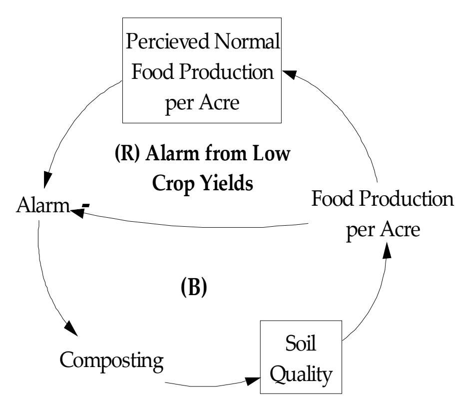


Figure 8: Food Production Alarm Generation

significantly, people should be motivated to compost or reduce resource usage to correct the problem. However, food production also suffers from an amnesia effect. Current food production is compared to remembered food production over the past five to sixty years.

These cues were fed into an "alarm" variable, which represented how concerned the populace was about their situation and how extreme the measures they take should be. The total alarm is a weighted average of these three cues. The cues are weighted by a set priority. In the initial test run, the priority on food shortages is 2, the priority on environmental degradation is 1.5 and the priority on crop yields is 0.75. These priorities can be changed as policy leverage point.

When the model is run with all three interventions enabled, the population again collapses. However, this time the there is extended peak population of about 60 years, providing a much more reasonable version of the collapse. It can be seen in figure 9, that natural resources again go to zero and food per capita declines from the start of the simulation.

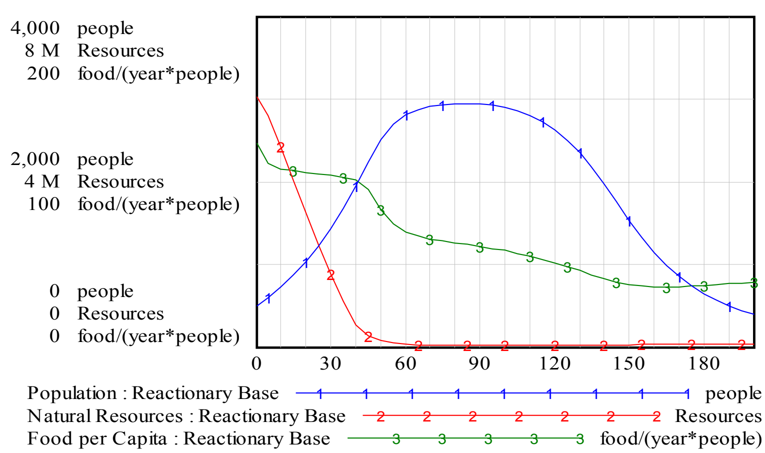


Figure 9: Cue Set One: Main Variables

Several tests were run to determine parameter sensitivity. These included extreme tests of the relative weights on each cue. In all of these tests the population still collapsed. Of particular interest were the tests on time to adjust birth rate, time to adjust expected crop yields and time adjust perceived normal levels of natural resources. Each of these was varied on a normal distribution from 5 to 60 years over 200 simulation runs as seen in figure 10, 11 and 12. These runs collectively establish that under no value of these variables could the society be sustainable.

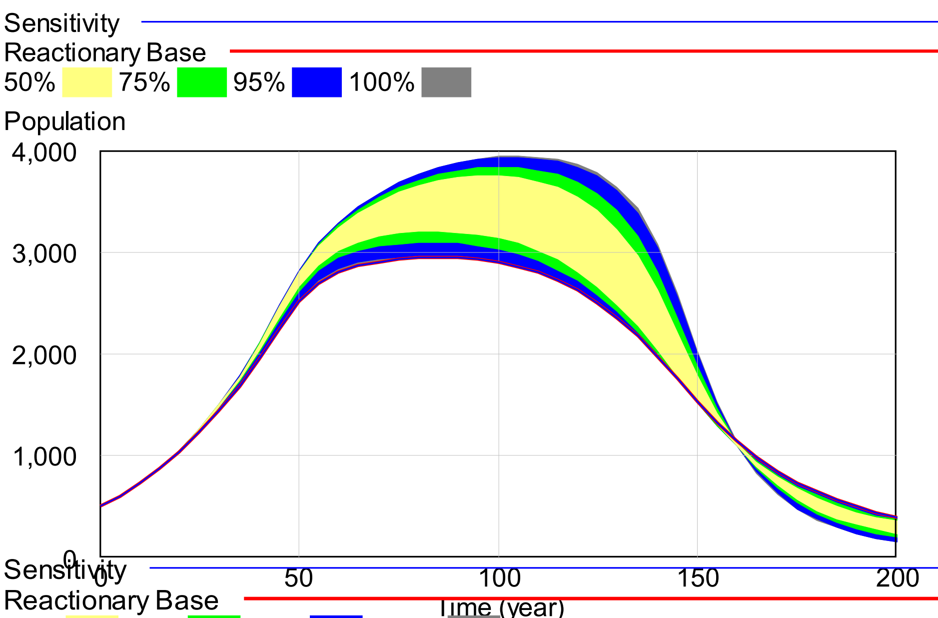


Figure 10: Time to Adjust Birth Rate Varied from 5 to 60 years

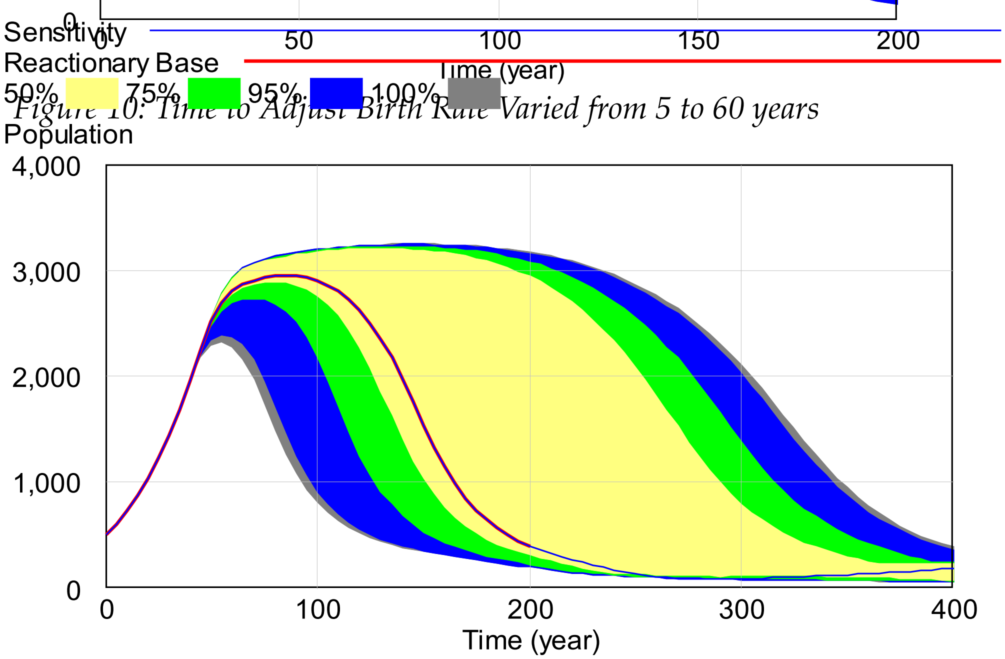


Figure 11: Time to Adjust Perception of Resources Varied from 5 to 60 Years

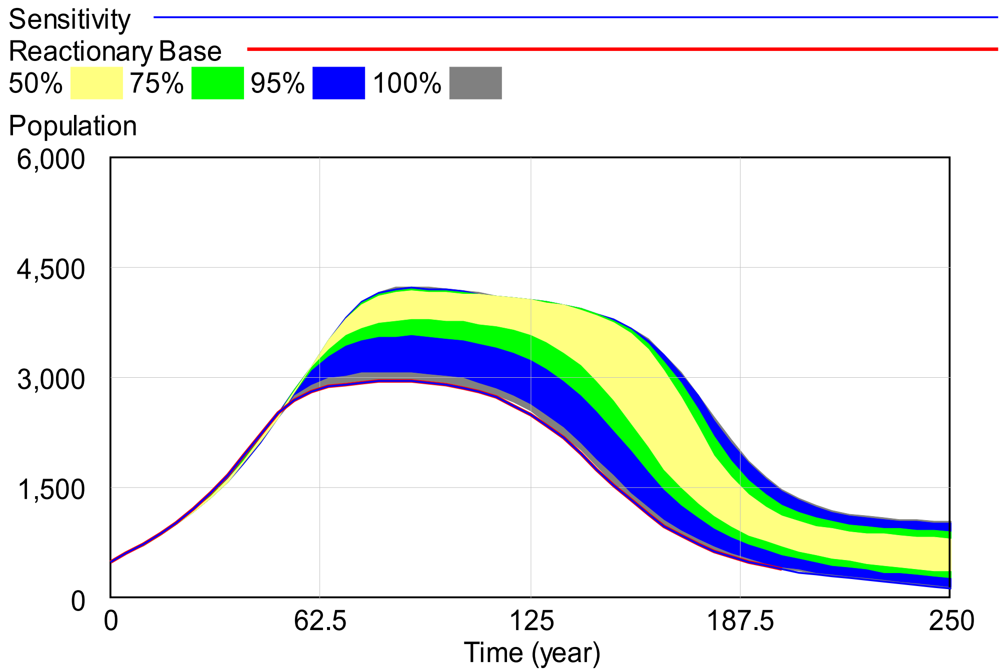


Figure 12: Time to Adjust Perception of Normal Food Production per Acre Varied from 5 to 60 years

Because no run produced a sustainable result, the New Guineans must have been using a different cue set to determine when to implement their policies. The next step was to look for an alternate set of cues that could produce the sustainable behavior observed in New Guinea.

Cue Set Two

In considering the failure of the first cue set, two factors came into play. First was the problem of eroding goals. The expected level of natural resources and food production per acre fell over time as people became accustomed to their current values. Such falling expectations undermined interventions intended to improve them by lowering the goal. The second problem was that of “too little, too late.” By the time soil quality had significantly degraded, the population had already reached an unsustainable size and a certain amount of backlash was inevitable. Finally, there was a problem of success undermining the efforts. Interventions were supported so long as alarm was high but as soon as they began working alarm would be reduced. Such a cue system ensures that there must always be symptoms or the interventions will not be sustained.

With this in mind, a new set of variables to use as cues was considered. Again the variable must be something the society could observe with a relatively low technology base. This time, though, additional criteria called for a cue that could not be subject to the eroding goals problem and that would remain as a behavior guide even when there were no symptoms. The first cue chosen was land fraction occupied. A target percentage of the land to be occupied by farmland and residential buildings was set and as the society approached this target it would implement family size control policies to slow and then halt population growth. This type of reference mode would not be subject to eroding goals.

The second cue was the gap between the amount of food a farmer needs to produce from his land and the amount he is actually producing. This reflects that composting can actually make farming more productive than otherwise healthy soil that had not received composting. The amount of composting was modeled as a stock with the amount be increased if yield fell below the needed value in a given year. Thus, farmers would experiment with composting to achieve a level that met their needs or they were composting the maximum feasible.

One other change was made in the land allocation method. Because of the target land fraction occupied goal, it not longer made sense to allocate the land between the three needs of farmland, residential and undeveloped. Therefore, allocation took place only between residential and farmland.

Using this second cue set, the society achieved a steady population. There is a slight overshoot of the population in the base run, but it does not collapse. Food per person declines in the beginning of the run but recovers as the society begins composting efforts to combat lower soil quality. Natural resources are again depleted, although they begin to recover towards the end of the model.

The quality of life indicators are normalized measure of quality of life variables, by dividing the desired value by the actual value, to make comparisons easier. The successfully society has high values for all indicators except resource usage. The resource usage indicator can be improved by lowering the target land fraction occupied to its sustainable level. However, there is no reason to suppose that the society would know what that level is.

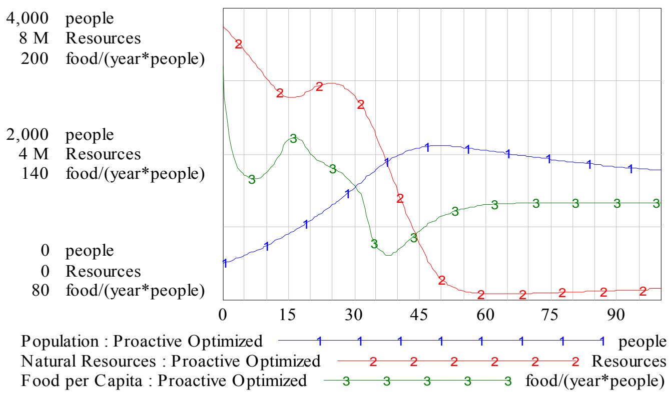


Figure 13: Cue Set Two: Main Variables

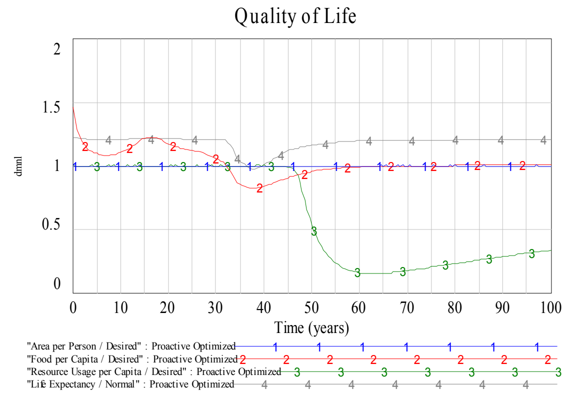


Figure 14:Cue Set Two: Quality of Life Indicators

The sensitivity analysis was repeated. The results are shown in figures 15 and 16 for the time to adjust birth rate and time to adjust perception of normal food production per acre. The sensitivity runs show that for all values of these variable the society is sustainable.

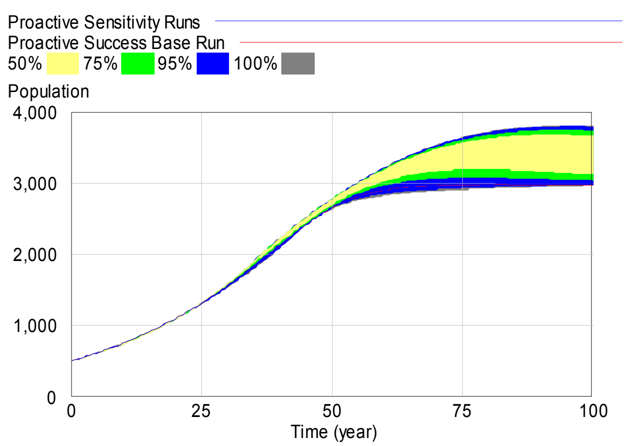


Figure 15: Time to adjust birth rate varied from 5 to 60 years

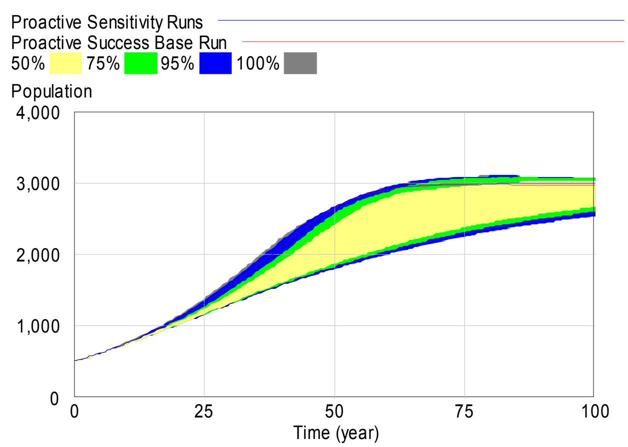


Figure 16: Time to adjust perceived normal food production per acre varied from 5 to 60 years

Discussion

Given the structure of the model, it has been shown that the successful society could not have used the first set of cues and may have used the second set of cues.

However, there may be other cues that could also result in success. It remains a question for further research to find evidence of which cues were actually used by the New Guineans to decide when to utilize their strategies.

The second question, which remains unaddressed by this model, is why one society would choose to use the good cues and another would choose to use the bad cues. It may be that the New Guineans had a clear territory, due to being on an island, while the Mayan's had less clear boundaries, or simply a better political process. The Mayans also had a much more complex civilization with food being imported into the cities. It is possible that with consumption of the food distant from the farmers, they could not easily determine what the desired production per acre would be. The question of whether these, or other, factors influenced which societies used successful cues in deciding when to implement policies for survival is again a question for future research.

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