Using Exact Sciences Models for Understanding Social Phenomena
Session 6 – The rise and fall of societies

Dr. Renana Peres,
School of Business Administration, The Hebrew University
Course # 55772

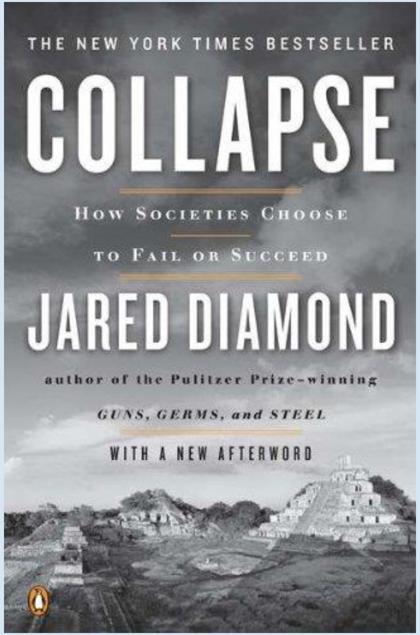
Societies rise and collapse

“What has been the fate of so many human beings, so long cut off from all intercourse with the more civilized world?.. Were they destroyed by an invasion of the natives … [or] perished by the inclemency of the climate, and the sterility of the soil?”

Hans Egede, a missionary, 1721

http://www.sciencemag.org/news/2016/11/why-did-greenland-s-vikings-disappear

What could be the reasons?



Human impact on the environment

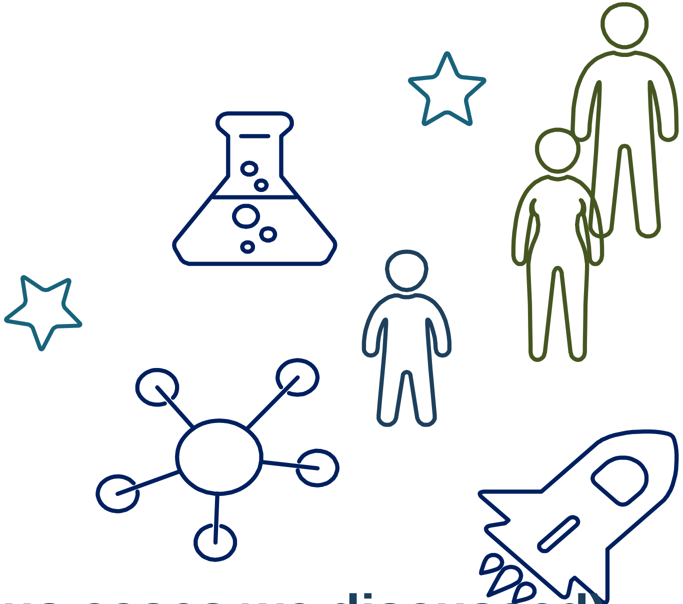
Climate change

Relations with neighbouring ***friendly*** societies

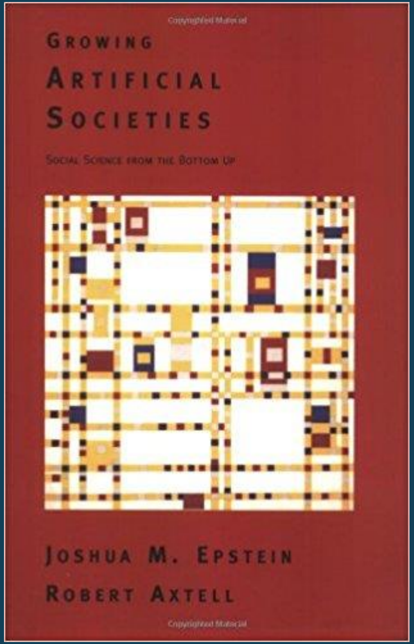
Relations with ***hostile*** societies

Political, economic, cultural and social factors

Can we find an alternative explanation?



- Can we come up (similar to the previous cases we discussed) with an explanation that is more self-emergent from the dynamics of the population?
- Can this alternative explanation teach us something on the suggested existing explanations?



The Sugarscape model

Epstein and Axtell 1996

Life and death on the Sugarscape

Setting
A single population gathers a renewable resource “sugar”, from its environment

Question 1
Can we observe a collapse of the population?

Question 2
What would be the distribution of wealth?

Answer 1
Yes

Answer 2
Highly skewed even if we start from a symmetric distribution

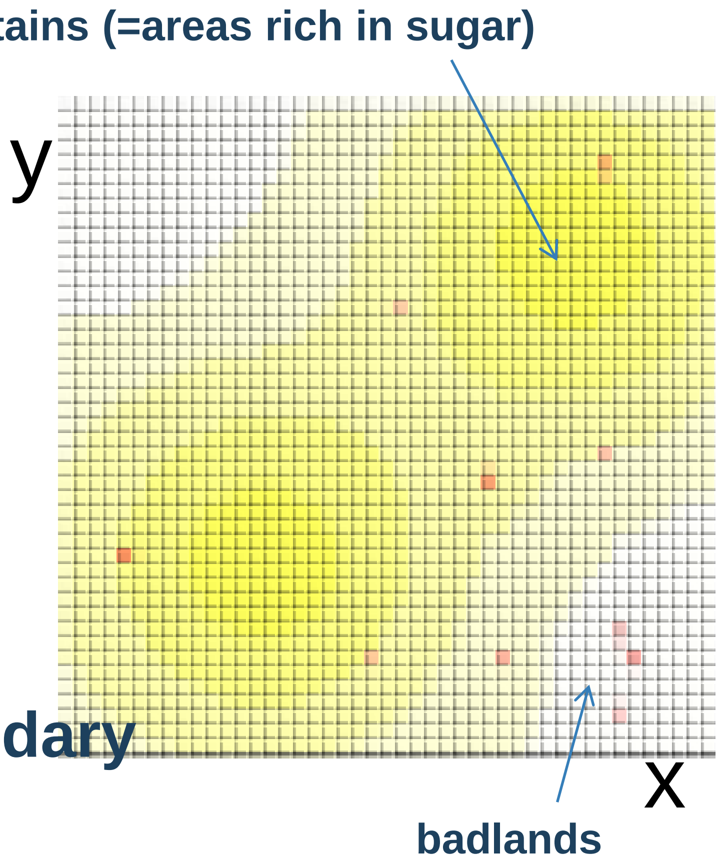
The Sugarscape structure

Sugar_capacity C(x,y) = max level of sugar

Sugar_Level l(x,y,t) = current level of sugar

A 50X50 grid, doughnut boundary conditions

l(x,y,0)=C(x,y)



Sugar consumption and regeneration

Individuals collect and consume sugar. The sugar regenerates.

Optional Rule 1
The sugar grows back to C(x,y) instantly

Optional Rule 2
The sugar grows back in different rates across regions.

Optional Rule 3
$G\alpha$= sugar regenerates at a rate of α units per time interval up to C(x,y).

$$l(x,y,t+1)= \min(l(x,y,t)+\alpha, C(x,y))$$

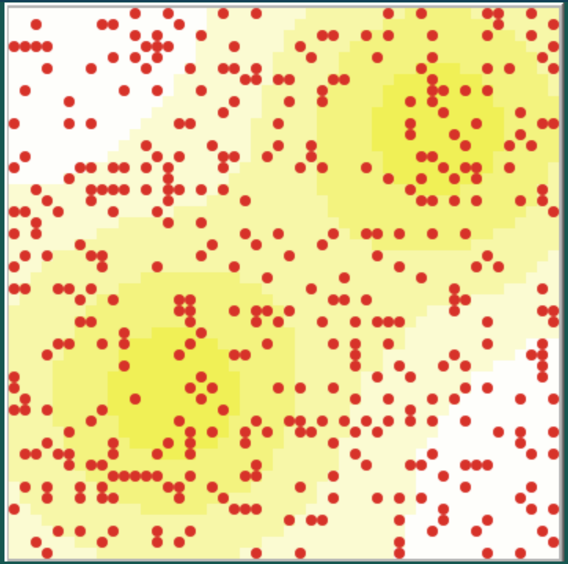
Other options?

The people

Gather sugar and eat it.

Sugar collected but not eaten is added to the agent’s sugar holding.

400 in our example (many empty spots)



Also termed “agents” therefore these models are also called agent based models.

An agent is described through a set of parameters and variables

Location (x,y)

1 agent per location. Agents are born in a random location.

Sugar metabolism

The amount of sugar consumed per time step. Randomly distributed across agents (here, discrete values of 1-4)

Vision

Agents with vision v can see v cells in each of the the four principal directions. Here, int 1-6. No diagonals.

Agent movement rule M

- Look out as far as vision permits in the four principal lattice directions and identify the unoccupied sites having the most sugar.
- If the greatest sugar value appears on multiple sites then select the nearest one.
- Move to the site.
- Collect all sugar at this new position.

Let’s play

Sugarscape rule option 1:
instant regeneration to C(x,y)

What happened?

Carrying Capacity

How much population can the environment keep in a good way.

Let’s play

Sugarscape rule option 3: Regeneration with rate α

What happened?

Wealth and its distribution in the agents population

Sugarscape rule option 3: Regeneration with rate α

To avoid going to infinity, agents have finite life span R, random between a and b. Here $R_{(60,100)}$

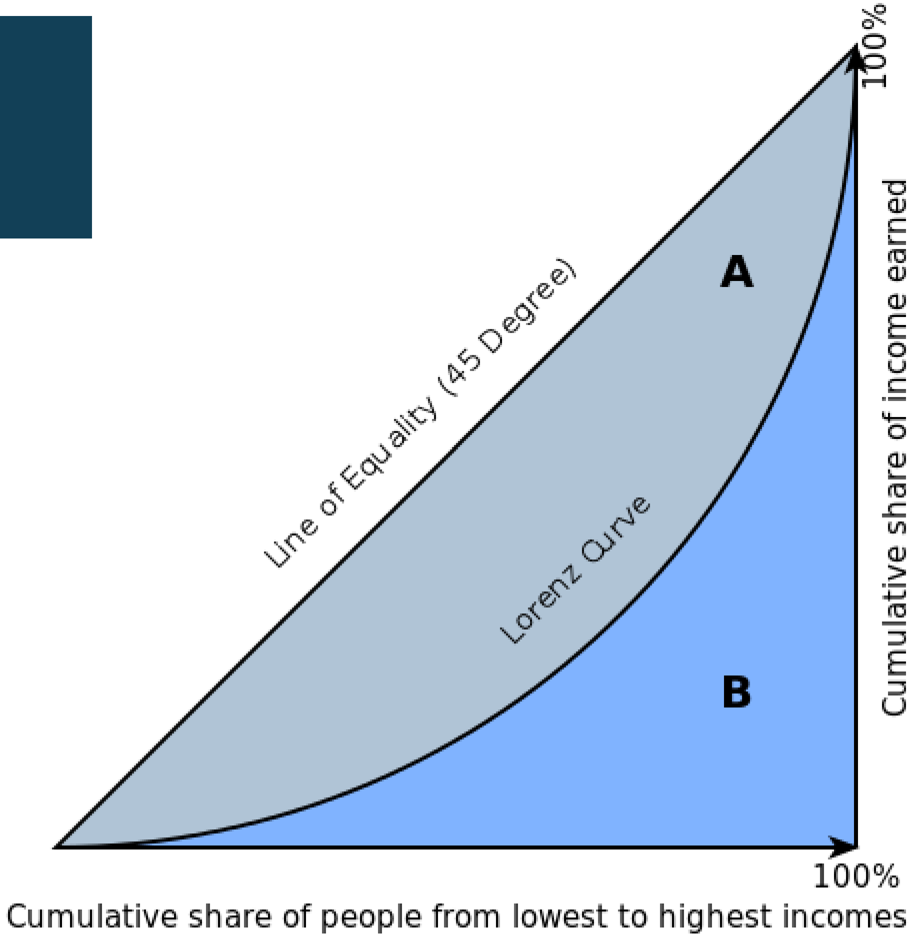
Let us focus on the distribution of wealth.
What happens? Why? What does it remind you?

Emergence

A stable macroscopic or aggregate pattern induced by the local interactions of the agents. Since it emerges from the bottom up we call it self-organization.

Measuring economic equality – The Gini Index

0 is all are equal
1 if one has it all



Measuring economic equality – The Gini Index

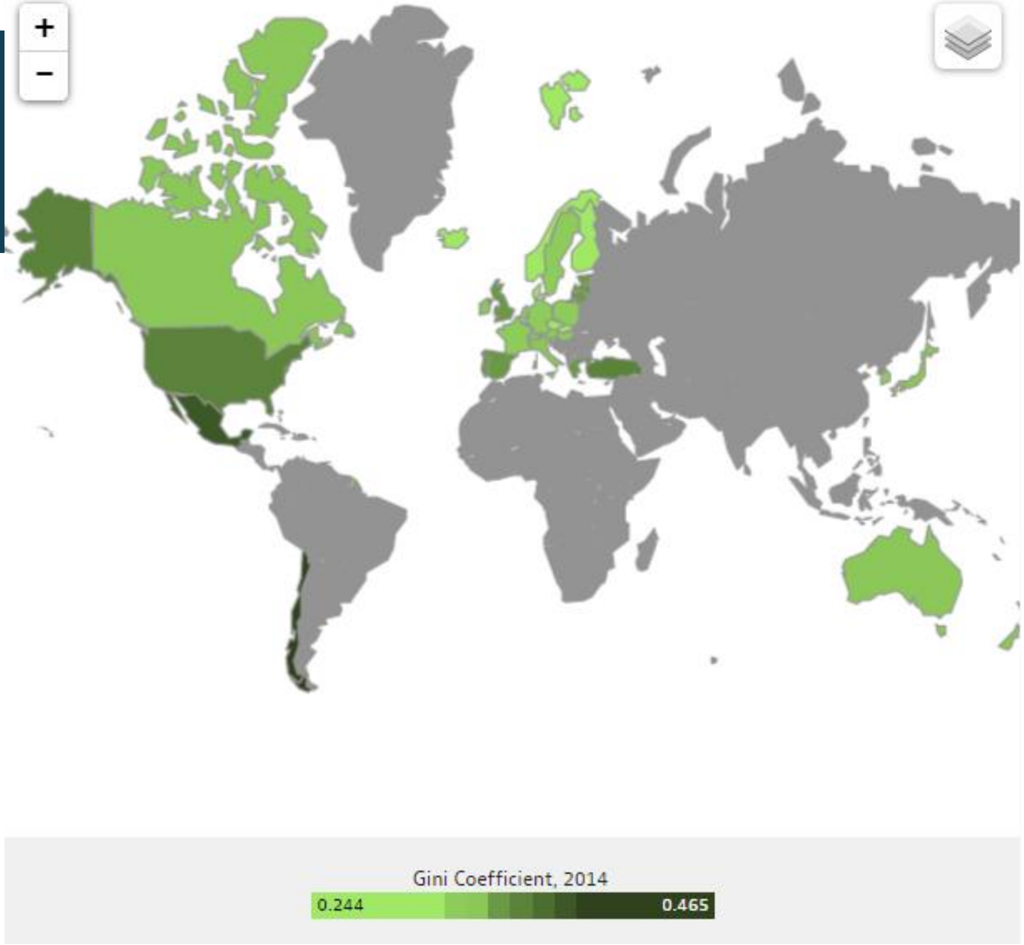
the mean absolute difference divided by the average, to normalize for scale. if x_i is the wealth or income of person *i*, and there are *n* persons, then the Gini coefficient *G* is given by:

$$G = \frac{\sum_{i=1}^{n}\sum_{j=1}^{n}|x_i - x_j|}{2\sum_{i=1}^{n}\sum_{j=1}^{n}x_j} = \frac{\sum_{i=1}^{n}\sum_{j=1}^{n}|x_i - x_j|}{2n\sum_{i=1}^{n}x_i}$$

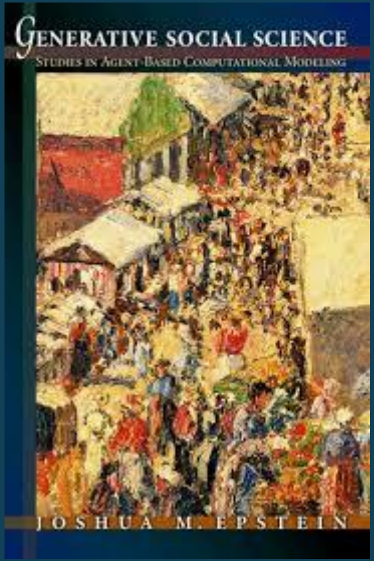
When the income (or wealth) distribution is given as a continuous probability distribution function *p(x)*, where *p(x)dx* is the fraction of the population with income *x* to *x*+*dx*, then the Gini coefficient is again half of the relative mean absolute difference:

$$G = \frac{1}{2\mu}\int_{-\infty}^{\infty}\int_{-\infty}^{\infty} p(x)p(y)\,|x-y|\,dx\,dy$$

where μ is the mean of the distribution $\mu = \int_{-\infty}^{\infty} x\,p(x)\,dx$ and the lower limits of integration may be replaced by zero when all incomes are positive.



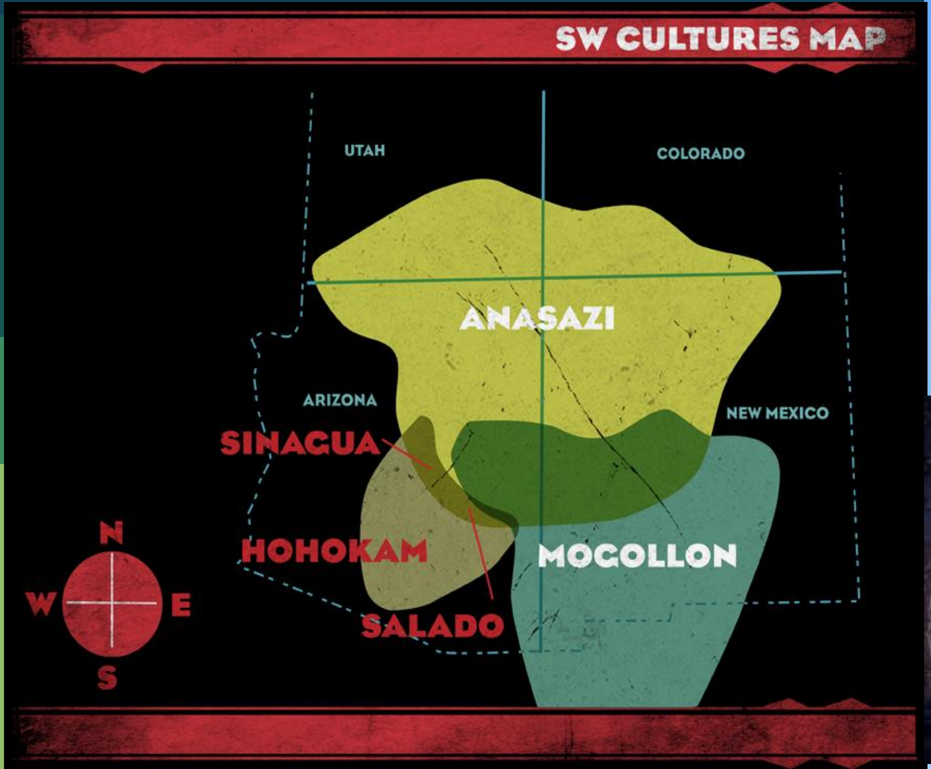
Country	Gini Coefficient, 2014
Chile	0.465*
Mexico	0.459
United States	0.394
Turkey	0.393*
Israel	0.365
Estonia	0.361*
United Kingdom	0.358*
Lithuania	0.353*
Latvia	0.352*
Spain	0.346*
Greece	0.343*
Portugal	0.342*
Australia	0.337
New Zealand	0.333*
Japan	0.33*
Italy	0.325*
Canada	0.322*
Ireland	0.309*
Denmark	0.254*
Norway	0.252*
Iceland	0.244*



The Artificial Anasazi

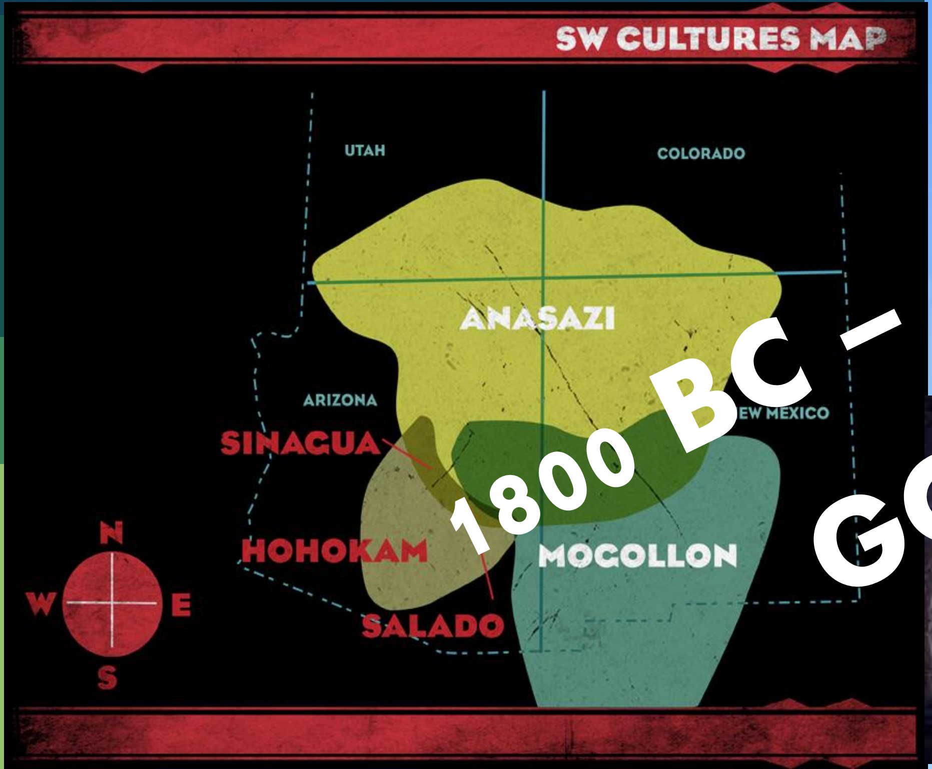
Epstein et al. 2000-2005

The story of the Anasazi



the ruins in Mesa Verde National Park

The story of the Anasazi




the ruins in Mesa Verde National Park

1800 BC – 1300 AD

GONE

Long House Valley, NE Arizona

96 sq km

Sugar == maize

Reconstruct archaeological data.

Explain why they disappeared

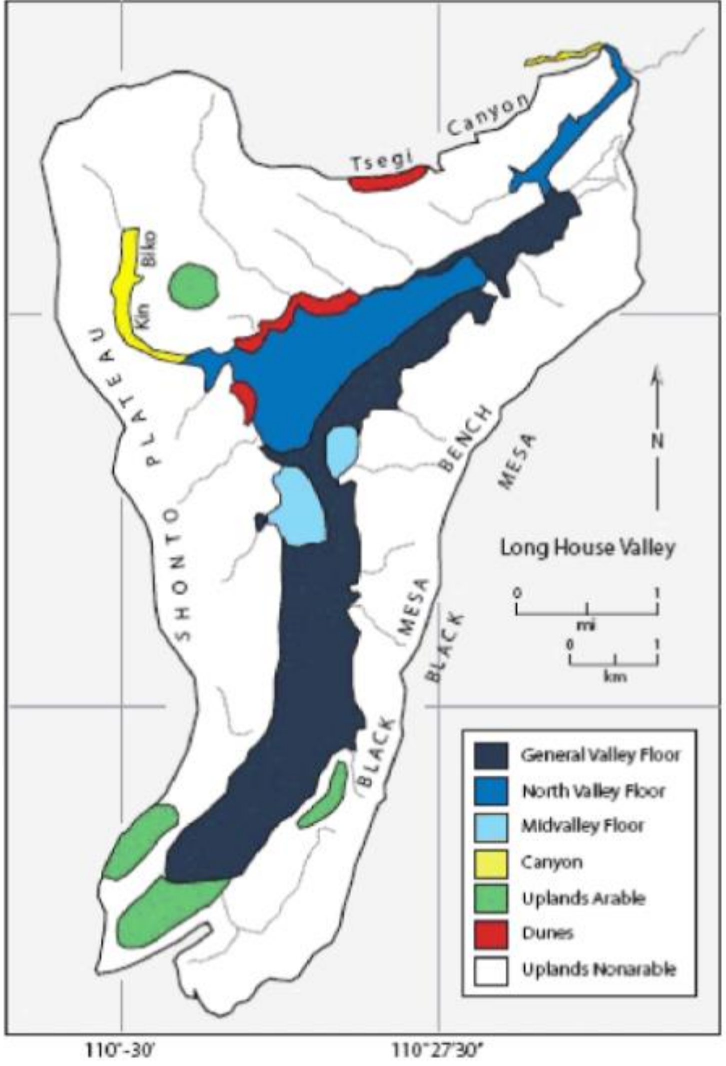
Common explanation – depletion of environmental resources.

The Maizescape structure

Each cell 100mX100m space.

7 production zones, each with its PDSI index

ADJUSTED PDSI	MAIZE YIELD (kilograms/hectare)			
	General Valley Floor[a]	North Valley Floor/Can[b]	Upland Areas[c]	Sand Dune Areas[d]
3.00 to ∞	961	1153	769	1201
1.00 to 2.99	824	988	659	1030
−0.99 to 0.99	684	821	547	855
−2.99 to −1.00	599	719	479	749
−∞ to −3.00	514	617	411	642



Agents attributes

Agent

A household of 5 people.
All household are identical

Harvest & Consume

Harvest everything they could grow.
Consume 800kg a year.
Store what is not eaten up to 2 years

Decisions

Where to farm
Where to settle

Reproduction

After age 16 a probability of 0.125 of starting a new household with a woman from another household.

Death

Age 30
or no food

Agent movement rule

- Estimate the amount of grains next year based on harvest + storage. If below the need – move.
- Farm – move to the most productive land that is available within 1600 m of a water source.
- Settle – Location nearest the farmland that contains a water source – option for several households at the same settlement.

The simulation

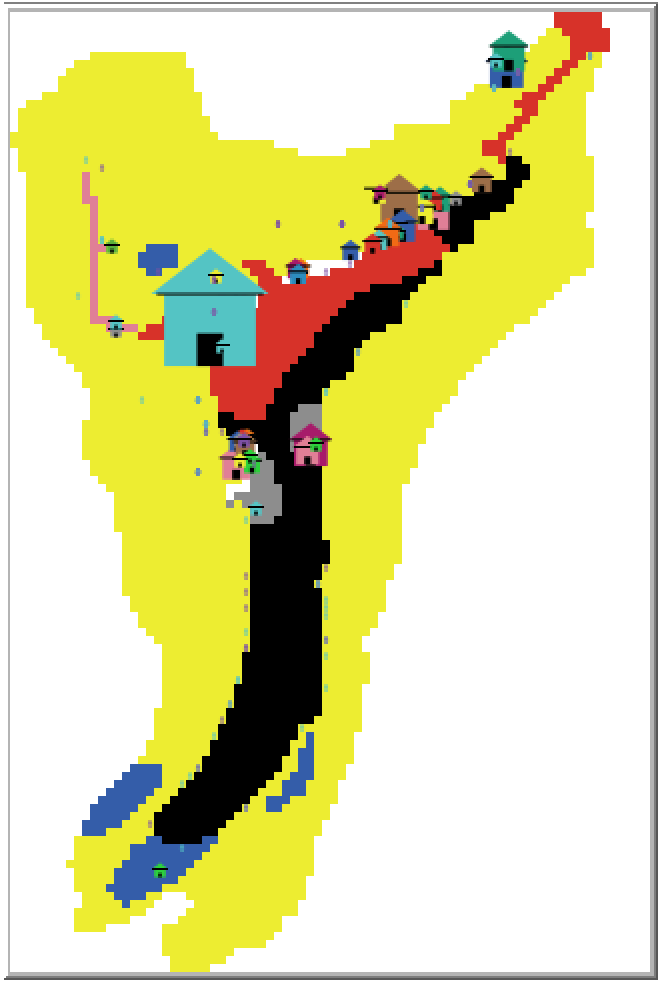
TABLE 4.2
Long House Valley Model Parameter Summary

Parameter	*Value*
Random seed	Varies
Simulation begin year	A.D. 800
Simulation termination year	A.D. 1350
Minimum nutritional need	800 kg
Maximum nutritional need	800 kg
Maximum length of grain storage	2 yr
Harvest adjustment	1.00
Harvest variance, year-to-year	0.10
Harvest variance, location-to-location	0.10
Minimum household fission age	16 yr
Maximum household age (death age)	30 yr
Fertility (chance of fission)	0.125
Grain store given to child household	0.33
Maximum farm-to-residence distance	1,600 m
Minimum initial corn stocks	2,000 kg
Maximum initial corn stocks	2,400 kg
Minimum initial agent age	0 yr
Maximum initial agent age	29 yr

Let’s play

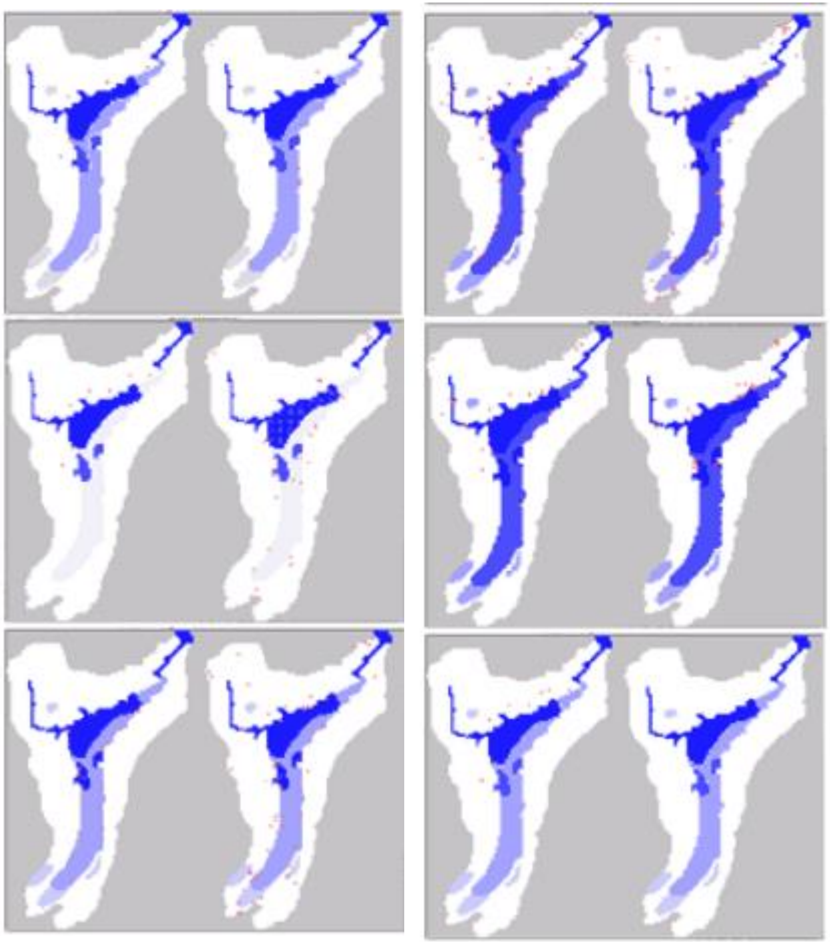
What happened?

Explain



Results

Environmental hardship does not, at least in this model, explain the final disappearance. A steep decline, yes; but a small population could have stayed.



Let’s discuss

What is the main takeaway from this modeling technique relative to previous ones?