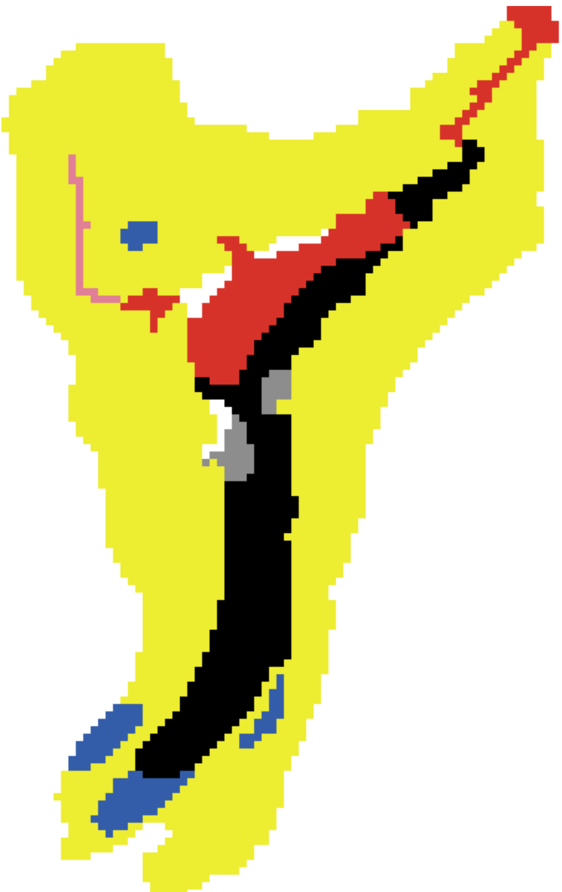
ODD of Netlogo implementation of Artificial Anasazi
1/17/2013

The model description follows the ODD protocol for describing individual- and agent-based models (Grimm et al. 2006) and consists of seven elements. The first three elements provide an overview, the fourth element explains general concepts underlying the model's design, and the remaining three elements provide details.
The model described is the Artificial Anasazi model as reported in Dean et al. (2000), Axtell et al. (2002) and Gumerman et al. (2003).

Purpose
The purpose of this model is to explore the causes of the indirectly observed population dynamics in the Long house Valley in Arizona between 800 and 1400. Does the environmental variability itself explain the abandonment of the Anasazi of the Long House Valley? Does a simple model of household rules on choosing locations for farms and settlements can reproduce the archaeological records of occupation in Long House Valley?

State variables and scales
Each agent represents a household of 5 persons. Each household makes annual decisions on where to farm and where to settle.
The attributes of a household:
- age,
- harvest during the last year
- estimated amount of food for current year
- fertilityAge (when household splits off a new household)
- stock of corn left over from pervious years
- nutritionneed, which is the amount of food a household needs a year..



Each cell represents a 100mx100m space. Each cell is within one of the different zones of land: General Valley Floor, North Valley Floor, Midvalley Floor, Arable Uplands, Uplands Nonarable, Kinbiko Canyon or Dunes. These zones have agricultural productivity that is determined by the Palmer Drought Severity Index (PDSI) as discussed later.

Figure 1: Different zones of land cover:

Black: General Valley Floor
Red: North Valley Floor
White: Mid and North Dunes
Gray: Midvalley Floor
Yellow: Nonarable Uplands
Blue: Arable Uplands
Pink: Kinbiko Canyon

A household also has a physical place to live, which is called a settlement. Such a settlement can be occupied by multiple households.

Process overview and scheduling

Every year the following sequence of calculations is performed:

1. calculate the harvest for each household
2. if agent derives not sufficient food from harvest and storage or the age is beyond maximum age of household the agent is removed from the system
3. calculate the estimated harvest for next year based on corn in stock and actual harvest from current year
4. agents who expect not to derive the required amount of food next year will move to a new farm location.
5. find a farm plot
6. find a plot to settle nearby
7. If a household is older than the minimum fission age, there is a probability p_f, that a new household is generated. The new household will derive an endowment of a fraction f_{cs} of the corn stock.
8. Update water sources based on input data
9. Household ages with one year.

Design concepts

Adaptation. Agents adjust the location of farming and housing if they expect that current location is not sufficient next year.

Fitness. Fitness of agent is determined by the amount of harvest derived and amount of corn in storage. An agent is fit or not. If not sufficient food is available, it is removed from the system.

Prediction. The prediction of harvest next year is the same as the experienced harvest from this year.

Interaction. Agents do not interact directly. Indirectly they interact by occupying potential farm plot. Agents are also marrying but this is implemented implicitly. In fact a household can derive an offspring at a certain agents, representing that the daughter leaves the house and starts a new household (immediately with 3 children that require 160 kg corn per year)

Stochasticity. Initial conditions of cells and agents, and the order in which agents are updated.

Initialization

The initial number of households is 14. Each household is initialized by setting a household age from the uniform distribution [0, 29] and by setting the value of the corn stocks by the uniform distribution [2000, 2400].

The quality of the soil of the cells is initialized by adding a number drawn from the distribution n(0, σ_{shv}) where σ_{shv} is the spatial harvest variance.

Input

A number of files are imported with input data. Input data provides information which cells are water sources for which periods (rivers, wells, etc.). The following data files are imported.

map.txt

- defines for each cell what kind of landcover zone it belongs to: (General Valley Floor, North Valley Floor, Midvalley Floor, Arable Uplands, Uplands Nonarable, Kinbiko Canyon or Dunes) adjustedPDSI.txt

- defines for each year and each category of landcover what the value of the adjusted Palmer Drought Severity is. This index is provide measurements of moisture conditions for agricultural activities.

Table 1: Classifications of Palmer Drought Severity Index

Value	Classifications of Palmer Drought Severity Index
4.0 or more	extremely wet
3.0 to 3.99	Very wet
2.0 to 2.99	Moderately wet
1.0 to 1.99	Slightly wet
0.5 to 0.99	Incipient wet spell
0.49 to -0.49	Near normal
-0.5 to -0.99	Incipient dry spell
-1.0 to -1.99	Mild drought
-2.0 to -2.99	Moderate drought
-3.0 to -3.99	Severe drought
-4.0 or less	Extreme drought

environment.txt

- the description for each cell which zone it relates to and when the cell is a water source.

settlement.txt

- contains estimates for each escavated settlement the time period of occupation and population numbers during this period

water.txt

- defines locations of water points and period in which they contain water

Furthermore, we have the following parameter values:

Table 2: Main parameters of the Artificial Anasazi model and their default values

Variable	value
Simulation period	800 AD to 1350 AD
Nutritional need per household	800 kg per year
Number of individuals per household	5 persons
Maximum length of corn storage	2 years
Harvest adjustment	1.00
Annual variance in harvest	0.1
Spatial variance in harvest	0.1
Minimum household age for fission	16 years
Maximum household age for fission	30 years
Household age for death (maximum age household)	30 years
Annual probability of fission p_f	0.125
Corn stock given to new household f_{cs}	0.33
Maximum distance between residence and farm	1600m

Submodels

We will discuss some steps of the model in more detail. The baseyield BY is defined by the yield y, quality of the soils in the cell q and the harvest adjustment level H_a,

$BY = y * q * H_a$

Where yield y is defined for each zone and each PDSI index. For example, the zones North Valley, Mid Valley and Kinbiko Canyon have the same rules for yield:

IF PDSI >= 3.0 THEN y = 1153
IF 1 <= PDSI < 3.0 THEN y = 988
IF -1 < PDSI < 1 THEN y = 821
IF -3 < PDSI <= -1 THEN y = 719
IF PDSI <= -3 THEN y = 617

The harvest of a household H_0 is equal to the baseyield of the location BY adjusted by some annual variation of the harvest using a normal distribution and a standard deviation σ_{ahv}
$H_0 = BY * (1 + n(0,\sigma_{ahv}))$

Before determining how much households consume, we need to define how much food is available. Every year, the stock of two years ago not used is disregarded. Subsequently the stock of 1 year ago S_{-1} will become the stock of 2 years ago S_{-2}, and the harvest of the current year will be input for S_0:
$S_{-2} = S_{-1}$
$S_{-1} = S_0$
$S_0 = H_0$

A household needs to derive 800 kg a year.
We start with a nutrition need remaining NNR = 800

If S_{-2} >= NNR THEN
    $S_{-2} = S_{-2} – NNR$
    NNR=0
ELSE
    $NNR = NNR – S_{-2}$
    $S_{-2} = 0$
If S_{-1} >= NNR THEN
    $S_{-1} = S_{-1} – NNR$
    NNR=0
ELSE
    $NNR = NNR – S_{-1}$
    $S_{-1} = 0$
If S_0 >= NNR THEN
    $S_0 = S_0 – NNR$
    NNR=0
ELSE
    $NNR = NNR – S_0$
    $S_0 = 0$

If NNR > 0 the agent is removed from the system

In order to determine whether the agent should stay or go it estimates the harvest for next year on the same location. This estimation is the amount of stored corn left plus the expected harvest (equal to current harvest level):

$E[H] = S_0 + S_{-1} + H_0$

Searching for a new farm is performed by identifying all unoccupied cells which produce more than the minimum nutrition requirement (800 kg) which are within 1 mile from a water source. If there are multiple suitable locations, chose the one closest to the current location

Searching for a settlement is performed by executing the following conditions:

i. The settlement location must be unfarmed (although it may be inhabited, i.e., multihousehold sites permitted).
ii. The settlement must be within 1 mile of the new aggricultural plot selected.
iii. The settlement must be in a less productive zone than the new agricultural land selected.

If multiple sites satisfy these above criteria the location closest to the water resources is selected.

If no site meets these criteria then first one looks at locations that meet condition i and ii. If still no site meets the criteria only sites who meet condition i are selected. Finally, if still no location is found, the agent leaves the system (which should not happen since the agent had already a settlement it came from).

Implementation

The Ascape 5.0.1 implementation available at http://sourceforge.net/projects/ascape/ is used to replicate the model in Net Logo 4.0.2. Unfortunately, the Ascape implementation is not well documented, and not well commented. We are however able to replicate the basic features of the model as discussed below. If errors are found in the implementation, please let me know: Marco.Janssen@asu.edu

Below we show the simulated population levels as published in Axtell et al. (2002) (Figure 2a), the default results of the model in Ascape 5.0.1 (Figure 2b) when the parameters are set to those described in Axtell et al. (2002), and the Net Logo implementation for the same parameter setting and the best of 100 runs using the L2 norm (Figure 2c).

Figure 2a

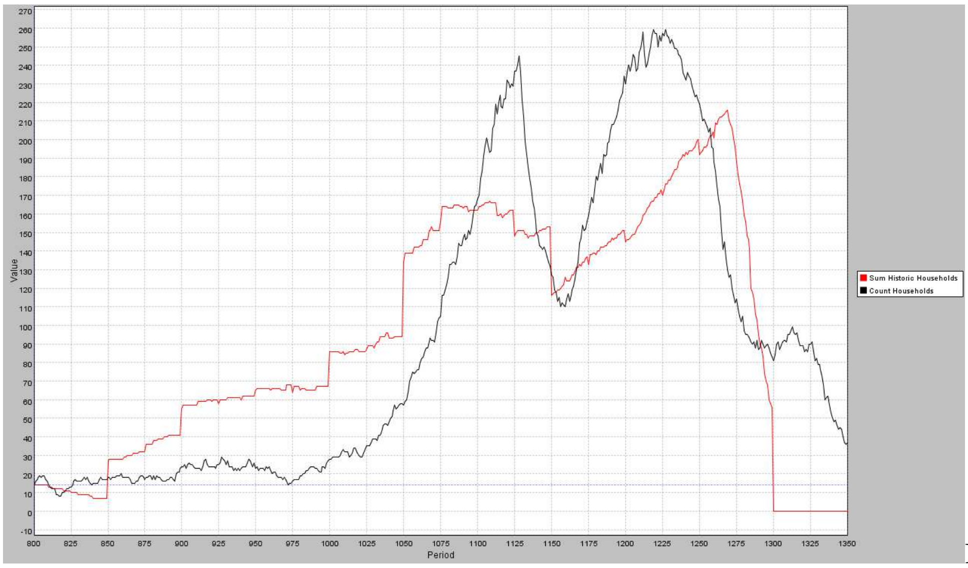


Figure 2b

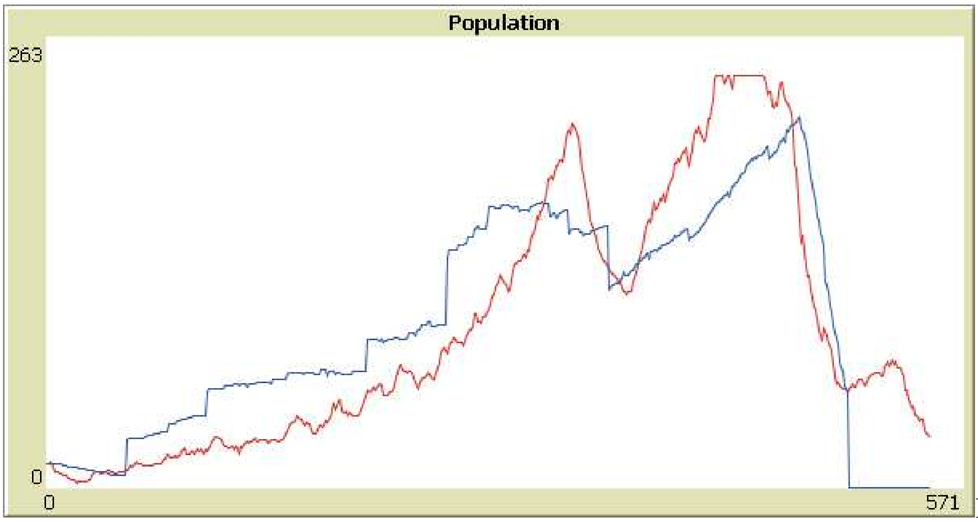


Figure 2c

References

Axtell R L, Epstein J M, Dean J S, Gumerman G J, Swedlund A C, Harburger J, Chakravarty S, Hammond R, Parker J, and Parker M. (2002) Population Growth and Collapse in a Multi-Agent Model of the Kayenta Anasazi in Long House Valley. *Proceedings of the National Academy of Sciences of the United States of America* 99(3): 7275-7279.

Dean J S, Gumerman G J, Epstein J M, Axtell R L, Swedlund A C, Parker M T, and McCarroll S. (2000) *Understanding Anasazi Culture Change Through Agent Based Modeling in Dynamics in Human and Primate Societies: Agent Based Modeling of Social and Spatial Processes*, T. Kohler and G. Gumerman (eds.), Santa Fe Institute. New York & London: Oxford University Press.

Grimm V, Berger U, Bastiansen F, Eliassen S, Ginot V, Giske J, Goss-Custard J, Grand T, Heinz S, Huse G, Huth A, Jepsen J U, Jørgensen C, Mooij W M, Müller B, Pe’er G, Piou C, Railsback S F, Robbins A M, Robbins M M, Rossmanith E, Rüger N, Strand E, Souissi S, Stillman R A, Vabø R, Visser U, DeAngelis D L. (2006) A standard protocol for describing individual-based and agent-based models. *Ecological Modelling* 198:115-126.

Gumerman G J, Swedlund A C, Dean J S, and Epstein J M (2003) The Evolution of Social Behavior in the Prehistoric American Southwest. *Artificial Life* 9: 435-444