Modeling of Agropastoral Human Activities Using Agent-Based Simulation

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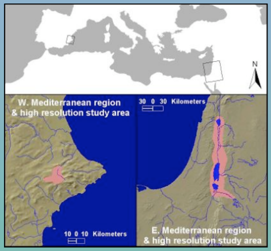
Introduction

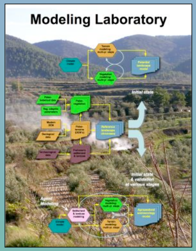
The multidisciplinary Mediterranean Landscape Dynamics Project studies effects of agropastoral activities on landscapes and societies from the Neolithic through the Bronze Age in the Mediterranean Basin. In this project, an agent model captures human social structure at the village and household levels. By encapsulating landscape data within a surface process model and creating an interface to the human agents, both models can perform independently and still react to the actions of the other, potentially offering new insights into patterns and long-term consequences of human land use.

Mediterranean Landscape Dynamics Project (MEDLAND)

MEDLAND is an **international, interdisciplinary research** project supported by the National Science Foundation ERE Biocomplexity in the Environment program (Grant #BCS-0410269). Teams of researchers from the disciplines of Anthropology, Geology, Geography, and Computer Science and Engineering are collaboratively studying the long-term dynamics of human land use in the Mediterranean Basin.

Website: http://www.asu.edu/clas/shesc/projects/medland/





Objectives

The MEDLAND project's main objective is to **study the long-term impacts of human agropastoral activities** on the landscape and on human societies from the Neolithic through the Early Bronze Age through the use of **landscape modeling and agent-based simulation modeling of human societies**. The project focuses on the achievement of this objective through investigating **three primary themes of human land use:** 1) The effects of growth in agropastoral economies on biodiversity, 2) Subsequent land use intensification and diversification and its impacts on landscape vulnerability and resilience, and 3) Studying the sustainability of human-maintained ecosystems. **Additional questions of interest** include investigating how land degradation impacts subsequent settlement patterns, how changes in agricultural practices affect crop and landscape productivity, and whether periods of village abandonment are associated with climate change or human-caused degradation of the landscape.

Goals of First Phase of Modeling

The first agent-based model focuses on **modeling agricultural land use in the Jordan Valley** from the middle of Early Bronze Age I to the middle of Early Bronze Age II-III (ca. 3350 B.C.-2450 B.C.). This model is intended to predict the land area surrounding a Bronze Age village that would be subject to landscape modification as a result of crop cultivation—requiring a model that also incorporates population change through time and yields results that are consistent with anthropological data for settlement size and population density of Levantine Bronze Age villages.

Photograph courtesy of Isaac Ullah, School of Human Evolution and Social Change, Arizona State University

Wadi Ziqlab, Jordan

Constructing an Initial Model Using Anthropological Data

Available data are most suitable for modeling Bronze Age agriculture in the Southern Levant. The data include:

- Ancient agricultural texts (especially from Syria and Upper Mesopotamia)
- Archaeological data from Levantine Bronze Age settlements
- Modern ethnographic studies of traditional Middle Eastern farming villages in Iran, Iraq, Syria, and Jordan that are potentially analogous to Bronze Age farming villages in population density and land use practices.

This data can be used to estimate model parameters such as settlement population densities, area of cultivated land surrounding a settlement, and rates of population change through time.

Interpretation of Settlement Data

Population Density:

The most appropriate data for estimating population density are provided by modern ethnographic studies, yielding estimates of 83-231 people/ha, with a mean of 159 people/ha. The data further suggest a household population of between 2 and 10 people per household, with an average of 5.5 people per household. Consequently, the value of 6 people per household was selected as the starting population for each household in the simulation model.

Per Capita Landholdings:

Data on per capita landholdings from appropriate modern ethnographic studies of villages from Iran, Iraq, Palestine, and Jordan were chosen to estimate per capita landholdings in the model. The data provide an estimate of 0.78-1.9 hectares per person, with a mean of 1.36 hectares per person. This includes land held for cultivating both annual and perennial crops (orchards). Therefore, the value of 1.36 hectares per person was utilized as the starting value for per capita landholdings in the simulation.

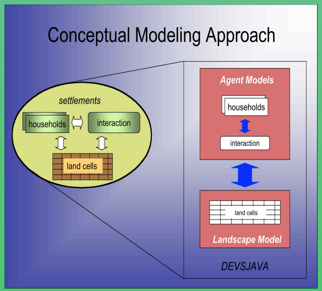
Rates of Population Change

Since creating a dynamic model of human land use is an important goal of the project, it is essential that the model include population change through time. Aggregate site area from Bronze Age settlements in the Jordan Valley was used as a proxy for measuring the regional population. The data suggest that, during the Early Bronze Age I-III, there was an overall decrease in population at an annual rate of –0.0565% and that, during the Middle Bronze IIA-IIB/C, there was an overall increase in population at an annual rate of 0.0833%.

Initial Agent-Based Model

The DEVSJAVA simulation environment [Arizona Center for Integrative Modeling and Simulation, http://www.acims.arizona.edu/] was chosen for simulating the agent-based model, and the agents within the initial model were defined as a human household with the joint goals of survival and reproduction. Within the simulation model, agents were able to perform actions such as managing crops, assessing current crop yields, and calculating their current population to determine food requirements. Crop management involves social rules for acquiring land for cultivation, following land, or releasing land. A cellular grid in DEVSJAVA represented the landscape in this initial simulation; each landscape cell within the grid represented a 0.5-hectare plot of land with dynamic soil values that decrease as a result of cultivation and increase as a result of fallowing. Landscape cells were additionally assigned values based upon their proximity to the village, such that landscape cells located closer to the village would be considered more desirable for cultivation by the agents.

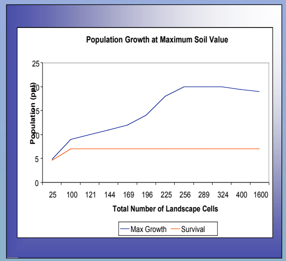
Determining how to accommodate details of social behavior within the limitations of settlement data and the constraints of modeling and simulation theory was the main challenge encountered during the development of the initial simulation model.



The above diagram illustrates how the real world system is abstracted into components that can be simulated within the constraints of Modeling & Simulation theory and the simulation engine. Diagram provided courtesy of the Arizona Center for Integrative Modeling and Simulation.

Simulation Results

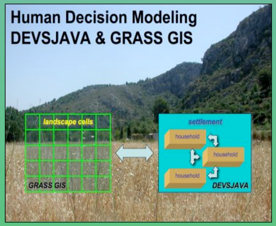
Results of the first simulation demonstrated that the simulation model behaves in a manner consistent with anthropological data and that simulating some models of human societies and landscape interactions in the DEVSJAVA simulation environment is possible. The simulation also displays some expected emergent behaviors: 1) Agent decisions resulted in contiguous land use around the village, 2) Agents alternated between cultivating and fallowing land plots, and 3) In times of low yield, agents released land (i.e. abandoned those particular plots) to acquire new, potentially more productive land farther away.



The above plot, showing the number of landscape cells versus household population, demonstrates that the simulation model yields the expected behavior that population growth is limited by the amount of available resources (cultivatable landscape cells). Plot provided courtesy of the Arizona Center for Integrative Modeling and Simulation.

Future Work

- Develop a general model that can be applied across the Mediterranean Basin and accounts for temporal and spatial variation in land use practices
  - Modeling of humans and the landscape thus far has depended heavily upon Middle Eastern data and Bronze Age settlements in the Southern Levant
  - Expand model to the Neolithic in the Jordan Valley
  - Develop a model of human land use in the Western Mediterranean (Spain) for the Neolithic through the Bronze Age
- Develop a more rigorous model of human land use in the Jordan Valley
  - Integration of a landscape model in the GRASS Geographical Information System with the agent-based simulation model in DEVSJAVA will contribute to this goal
- Develop a dynamic simulation model that produces emergent behaviors that correspond with observed data for the time periods and regions under study
- Model additional social dynamics—for example, kinship and marriage, trade, and interactions between settlements



Acknowledgements

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