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LA

Identifying Landuse Catchments for ancient settlements.

by Author 1 and Author 2

Introduction

This paper describes a software application we are developing that automates the process of computing landuse requirements and identifying the land likely to have been engaged by the people living in ancient settlements. The useage of the LA application is illustrated in this text using an archaeological site at Shuna (Figure 1) in the Jordan Valley. The Jordan Valley is found in the Southern Levant, which is a name commonly used to refer to the geographic region broadly described as modern-day Israel, Palestine and Jordan, between the Dead Sea and Lake Tiberias.

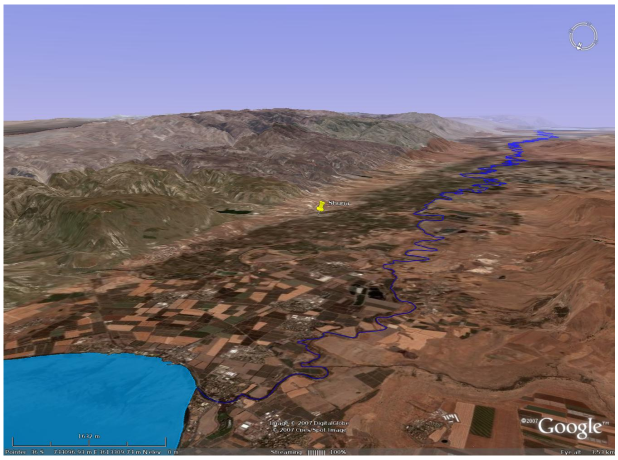

Figure 1: *Looking South-South-East from Lake Tiberias Down the Jordan Valley towards Shuna.*

Background

For an archaeologist, understanding the relationship that existed between people in the past and their landscape is very important. People throughout time have relied on various plants and animals, wild or

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domestic, to provide them with the food they require to survive. Regardless of the period in time being examined, a relationship exists between people and the space which they occupy. A better understanding of this relationship can help to more confidently theorise about a range of issues in the reconstruction of past societies. By piecing together clues gained through a combination of archaeological surveys, ethnoarchaeology, written records, oral traditions, and excavations, insights can be gained which can offer a more concrete understanding of the relationship people had with their landscapes, allowing archaeologists to better understand topics such as as short and long term impacts on the landscape, or social and economic organisation.

An understanding of long term impacts of ancient humans on their landscape can be useful for modern day researchers by providing insight into the potential environmental impact of current human activities. In modern societies, urban centres rely upon the surplus production of agricultural commodities provided by farmers in the countryside. This reliance necessitates a certain level of organisation between rural and urban people. By applying this same logic in historical contexts, we can infer landuse patterns.

Through careful study, a better understanding of the land use habits and patterns of these populations can unlock many interesting facets of culture and lifestyle. By examining seeds, bones, and other items found at archaeological sites, archaeologists are able to determine dietary habits. From the relative quantities found estimates can be made of the importance each food source would have had in the diet. The scale of production, for example, can help indicate whether crops were being cultivated for subsistence use or for more commercial purposes. If there is evidence of surplus production of any particular crop or animal, this can be a possible indication that it was being grown commercially. Other possible inferences include taxation, storage, redistribution, intensified farming, and craft specialisation, all of which can indicate increased economic complexity.

Process for computing landuse requirements

To learn more about how people interacted with their land, it is helpful to determine the area of land needed to support settlement populations and its likely distribution. To locate the land being used, it is necessary to first know how *much* land would have been needed to produce enough food to sustain the settlement. Once this target for the area of land has been determined, the land surrounding the site must be classified as either suitable or unsuitable for each crop sown and each type of animal being raised. The final, resultant map which LA produces, is a compilation of individual maps from each crop and animal, for which sufficient suitable land has been identified to meet the settlement's production requirements.

Moving to a GUI

In 2006, a BASH script was created running in a GRASS shell. This script found a specific area of classified, suitable land surrounding a point by starting at a point and moving outwards in a circle five meters at a time, checking each time to see if there was enough suitable land contained within the perimeter. As soon as it was equal to or greater than the target area, the loop was ended, and the solution was deemed found.

The complexity of the animal and crop modelling made using BASH scripts very awkward. While the BASH scripting approach worked well for a proof of concept, the implementation included a large number of hard coded variables and the solution did not provide a flexible environment for experimentation. For example, adding, removing or even editing different types of crops and animals to the analysis required heavy modifications to the BASH script. The BASH script approach also had poor reporting capabilities and offered little 'hand holding' to the user as the analysis was carried out.

Consequently we commenced development of a Graphical User Interface (GUI) based application (Figure 2), written in C++ and Qt4. This programming environment decision was largely motivated by a desire to capitalise on existing code bases from openModeller[1] and Quantum GIS (QGIS)[2]. For invoking GRASS tools we opted to use QProcess to launch GRASS commands in their own process and then implemented application logic to parse the results of each command from stdout.

[1]openModeller is available at `http://openmodeller.sourceforge.net/`
[2]QGIS is available at `http://qgis.org`

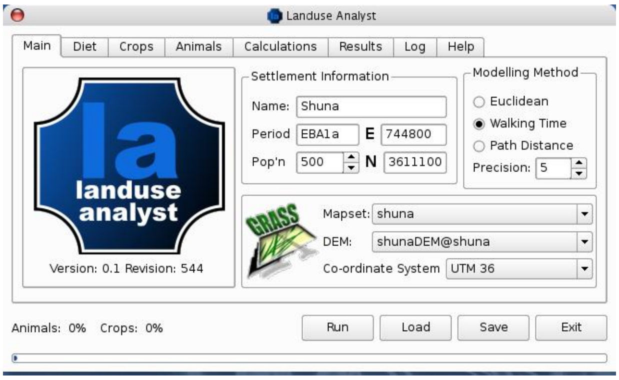

Figure 2: *LA's primary interface*

Analytical functionality

LA includes various routines for calculating the amount of land the settlement needs. Briefly, these can be outlined as follows:

1. Breaking down the basic diet of the community into specific crops and animals being used for nourishment. Each individual crop and animal needs to be expressed as a percentage of the peoples' diet. This is estimated using proportions based on archaeological evidence such as faunal and paleobotanical remains discovered during excavations.
2. Calculating calorie targets for the crops and animals identified above.
3. Calculating production targets which fulfil the calorie targets. Production targets are calculated in kilograms, and take into account factors such as calories per kilogram of produce, and what percentage of an animals weight is usable as food.
4. Calculating land area targets needed to satisfy the production targets. Each crop and animal is allocated a specific area target.
5. Carrying out a spatial analysis of the land surrounding the settlement to find land suitable for each crop and animal that satisfies the area targets.

Determining calorie targets

Calorie targets are the first level of calculations done by LA and are determined through a number of steps (Figure 3), which are as follows.

1. ***Basic Information*** - The user supplies LA with the population of the settlement, as well as the average daily calorific requirements of an average member of the population. By multiplying these figures, the total number of calories required for the settlement is calculated (Figure 6).
2. ***Primary Dietary Components*** - This step works on the principle that calories can come from only two fundamental sources: plants and animals.
3. ***Detailed Dietary Components*** - At this step, the process gets split into two sections. One section is for the Plant portion of the diet, and the other is for the Meat portion.
4. ***Crop/Animal Contributions*** - This value tells LA that this individual animal or crop comprises the indicated percentage of the calories being supplied by tame sources, which is the value from the previous step. Remember that this is a portion of the *tame crop* part of the diet! (See Fig. 4 and Fig.5).

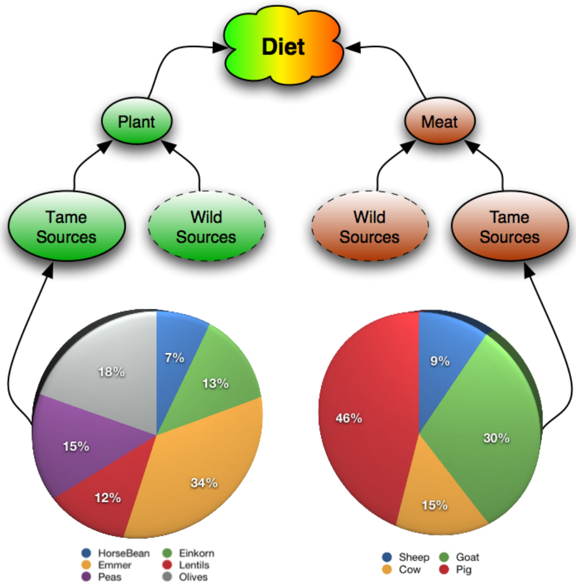

Figure 3: *Conceptual diagram of a settlement's diet composition.*

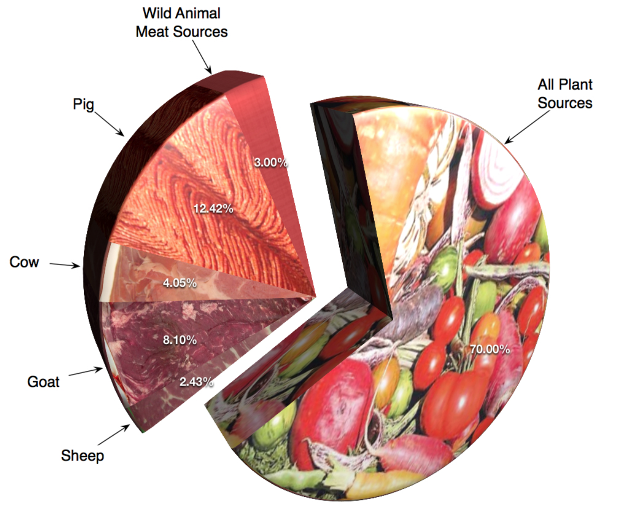

Figure 4: *Conceptual diagram of meat component of diet.*

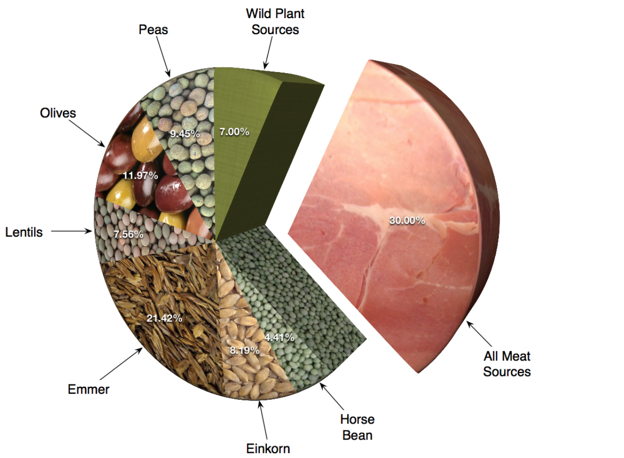

Figure 5: *Conceptual diagram of the plant component of diet. Note that the input figures for percent of diet were:* ***HorseBean*** 7%, ***Einkorn*** 13%, ***Emmer*** 34%, ***Lentils*** 12%, ***Peas*** 15%, ***Olives*** 18%. *These numbers translate to those shown above after processing as in Figure 3.*

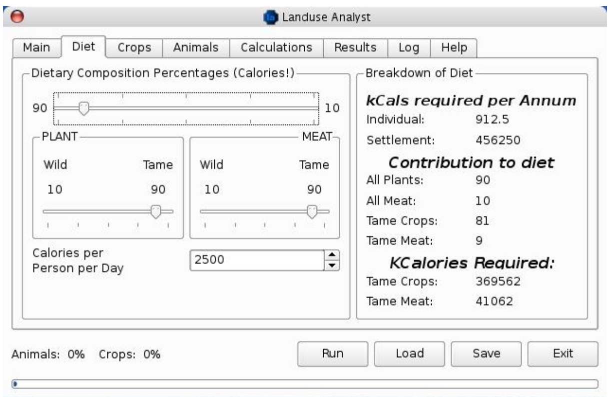

Figure 6: *Diet Tab, LA*

Determining Production Targets

Production targets are measures of weight, and represent how many Kg of each crop and animal must be produced to satisfy the calorie targets calculated above.

- **Crops** - The user must supply the food value for each crop. This is expressed as calories per kg. Using the calorie targets and the user supplied food value, the model calculates a production target for each crop that is necessary to meet these needs.

- **Animals** - When animals get slaughtered, and only part of their carcasses are usable as food. This usable part of their live weight is supplied by the users when they define the animal in the Animal Manager form, expressed as the percentage of their live weight which is usable as food.

Determining Area Targets

Once production targets are calculated, it is possible to calculate area targets for each crop and animal by looking at yield values for plants, and grazing requirements for animals. As with Production Targets, Area Targets are quite simple to compute for crops, but get very complicated for animals.

Defining Characteristics

Crops

A list of all crops that have been defined is found when the Crops tab is clicked (Figure 7). Note that the user has the choice of selecting it for inclusion in the model, as well as being able to select different parameters from a drop-down list. To the right of the drop down list is the crop's contribution to the tame plant portion of the diet using the currently selected parameter. The total of these percentages must be equal to 100% before the model will run, and the current total is always visible in the bottom left hand corner of the form.

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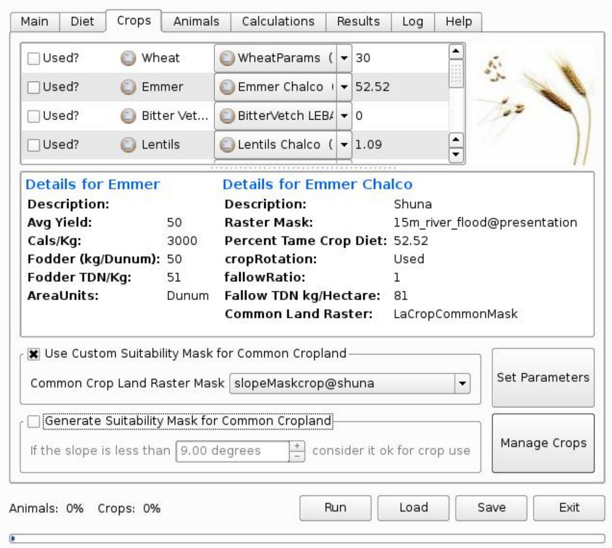

Figure 7: *Crops Tab, LA Version 0.1 Revision 544*

Defining Crops

Every crop has unique characteristics, and LA splits these defining qualities into two main areas: details of the plant and parameter settings.

Defining the Plants

LA uses seven input fields to define a plant (Fig.8).

Crop Parameters

Once you have defined the plants that are being grown as crops, Landuse Analyst needs to know the specifics of how each crop is being grown, as well as what portion of the settlement's diet it provides (Fig. 9). It must also know what land is capable of growing each crop by selecting either Common or Specific Land Suitability masks (keeping in mind that if Specific Land is selected, the Raster Mask must be selected from the drop down list). The two major entries, however, involve *crop rotation* and the selection of *suitability masks*.

Crop Rotation

A common farming technique still used widely even today is the practise of resting your cropland every growing season or so. This is called *crop rotation* (Figure 9) and is critical to the process of determining how much land is required for food production, as it can more than double the area target for a crop. Complicated crop rotations are possible in LA, and the process of setting this up are explained in detail in the Help section of the program itself.

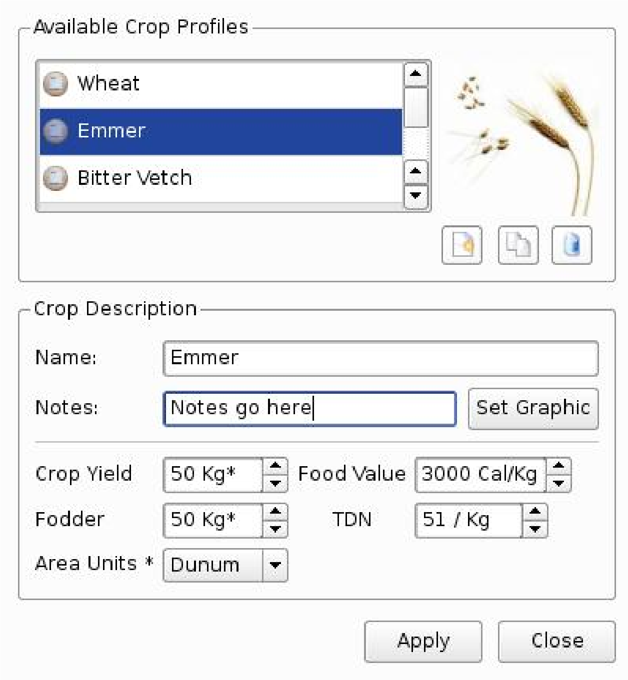

Figure 8: *Crop Manager, LA*

Another important aspect of defining crop rotation concerns animals. It is possible for animals to graze the fallow land, which will reduce the amount of grazing land otherwise required to sustain the animals. In order to know how much contribution the fallow land makes, it is necessary to know the food value of the fallow land. Using the ratio of crop land to fallow land along with the food value of the fallow land allows LA to accurately adjust the grazing land requirements for the animal herds. How this is done is explained in detail in the following section.

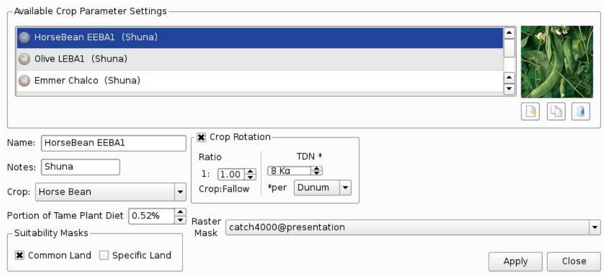

Figure 9: *Crop Parameters form for setting the particulars of the crop.*

Animals

Animals are difficult to calculate area targets for because their land requirements are largely based on their numbers, and a herd of adult females large enough to sustain a steady supply of offspring with numbers enough to keep the production targets met has to be added into the equation as well. In addition, animals can graze fallow crop land, eat fodder from the crops being grown, and graze other types of land. LA takes these interactions into account in its computations. Herd Size determination is perhaps the single most difficult calculation that LA performs. Added to the complexity of this is the problem that different animals have different dietary requirements, and even further, even if they are the same, they require different amounts of feed depending on things like whether they are pregnant or lactating. To further complicate the issue, not all land that can be grazed has the same food value to the animals.

LA does, however, address these issues. One of the first things a user must do when using Landuse Analust is to define all of the crops and animals that the settlement used. During this process the users provides information about aspects including (for animals) information relating to their dietary requirements, their reproduction cycle, and their grazing preferences.

Defining Animals

Animals present several challenges that plants do not. For starters, a certain number of females must be kept solely as breeding stock, and this number must be calculated based upon production requirements. Secondly, the possibility exists that part of the animals' diet was from either straw/chaff left over from harvesting crops, or directly from harvested grain. In the case of grain being used as feed, the amount used must be considered when determining the production targets for the crops. Thirdly,if crop rotation was happening and fallow land was present, there is the possibility that this was used as grazing land, and would therefore reduce the amount of natural grazing land required. This also adds complexity to the crop models because grazing fallow land adds fertiliser, potentially increasing yields. This phenomenon can be factored in to Landuse Analyst by manually adjusting the expected yield of the affected crops.

Version 0.1 of LA allows animals to use fodder as food. The amount of the contribution of fodder is expressed as an overall percentage of their diet in terms of calories. Furthermore, the model provides separate inputs for fodder (straw/chaff) as well as straight grain. When setting up the model, the user supplies fodder production levels for the crops, as well as caloric levels for the fodder.

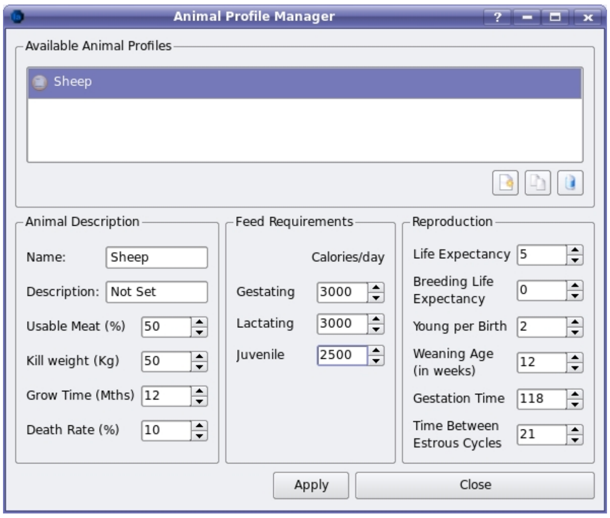

Figure 10: *Animal Manager, LA*

Animal Characteristics

LA uses several input variables to define an animal (Fig. 10). Two items which are worth further discussion are the Common and Specific Land options.

- ***Common Land*** - Sometimes land is suitable for grazing by more than one type of animal. LA allows you to designate one suitability mask as common grazing land. Note that you can specify an animal to use both common land and specific land at the same time. If this is the case, equal preference is given to all animals grazing the common land. This is not always ideal, as it may have been the case that some animals were given preference to the common land if the other suitable land was further away than the other animals using it. (A workaround for this problem is that LA produces classified maps of the land being used, so if it is the case that you find one animal being forced to travel much further than others, you can simply change the settings to balance this. This can be accomplished by removing the other animals one at a time from using the common grazing land. It may be the case, however, that there is no ideal solution, and that they simply had to travel the extra distance.)

- ***Specific Land*** - Sometimes you may want to specify that land is suitable for grazing by only one type of animal. LA allows you to designate a land suitability mask as being unique to that animal. Note that you can specify an animal to use both common land and specific land at the same time. For more detailed information on this, see the help section of LA.

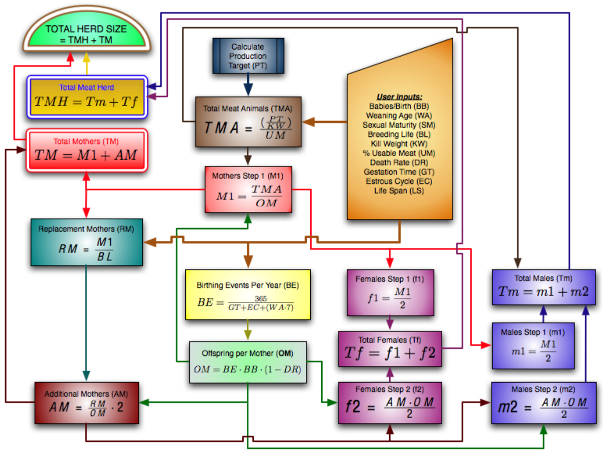

Figure 11: *Animal Herd Size Calculation - This diagram assumes that the production target has already been worked out. Units for input variables are:* ***WA****-days,* ***SM****-months,* ***BL****-years,* ***KW****-kg,* ***DR****-percentage,* ***GT****-days,* ***EC****-days,* ***LS****-years,* ***PT****-kg.*

Herd Size Calculation

The size of the herd required to sustain a particular amount of meat for a population is crucial for determining an area target for each type of animal raised. An algorithm generic enough to make this calculation for any animal that has been defined in LA was created. By taking the Production Target and several user inputs, the total number of adult females (Mothers) and animals being raised for meat (Meat Animals) can be approximated. This process is outlined in Fig. 11.

Land Redesignation

Another notable feature of LA is land redesignation. Land that is suitable for the production of crops is almost certainly suitable for grazing as well. For this reason, LA performs all of the cropland functions first. Once the area targets for all crops have been satisfied, all of the unallocated land previously classified for use by crops is redesignated as being suitable for common grazing land.

Catchment creation methods

When searching for land that meets the area targets, LA starts at the coordinates of the settlement and moves outward to a point where the land contained within equals the area target. LA implements three different methods for searching outwards from the settlement. The key difference between the three methods is the way in which a cost-surface is generated, which we will now examine. All three methods currently used by LA require a **D**igital **E**levation **M**odel (DEM) to generate the cost surfaces.

Euclidean

This method ignores all topographic features of the landscape when moving outwards from the site. Essentially we are drawing circles around the site, with the site right in the middle. Drawbacks to using this method exist. Whilst moving across a landscape, people are affected by slope, rivers, landcover, etc. Circles are just convenient when there is no easy way to calculate with an alternative method. The primary reason for its inclusion as a catchment area creation method in LA is to provide the user with the option of seeing the difference between this rather simplistic approach and the other two methods.

Path Distance

Path Distance is a cost surface creation method that looks at elevation data from a DEM and calculates distance from the site taking into account the extra distances travelled going up or down slopes.

Walking Time

Walking Time is likely going to be the primary choice of the three methods of creating catchment areas in LA. The cost surface that is generated for this method (Figure 12) uses a DEM to calculate how long it would take to walk from a starting point (the site, or ZERO on the cost surface) to all points on the DEM within a five hour walk (18,000 seconds). Five hours is simply the time used for this case study[3] This creates a cost surface with values from 0 to 18,000 (Figure 12).

[3] This number is currently hard coded. Future versions will allow the user to edit this value.

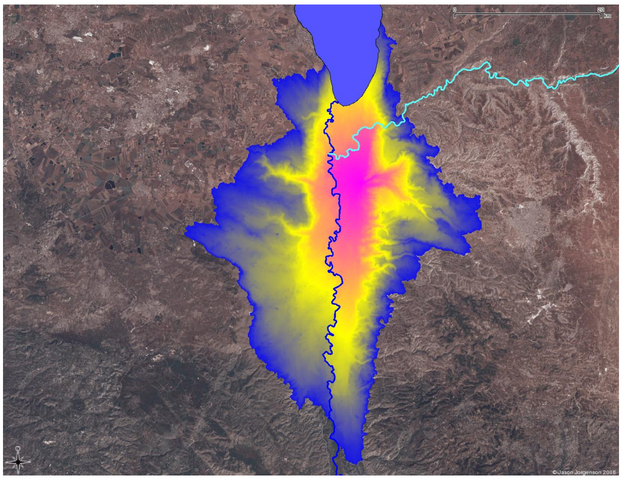

Figure 12: *LA generated this using the GRASS module r.walk.*

Land suitability raster masks

The land suitability masks must be binary rasters, meaning that the cells of the raster file only contain 0 or 1 (NULL values are currently not supported). The land that is deemed suitable for use should be set to a value of 1, and the rest of the land is set to 0. This binary raster can then be multiplied by a selection layer (as created by either Walking Distance, Path Distance, or Euclidean methods). This selection layer (also a binary raster) grows in size until enough area is found within it's bounds - identifying the land to be analysed.

In the current version, the software gives the option using three different methods for landuse classification. They are:

1. Use only the user supplied classification map (a binary mask)
2. Use minimum and maximum slope values to create a classification map which will be used exclusively. This can be done for common crop land and common grazing land independently. For example, the user might stipulate $0° \leq m \leq 9°$ for crops and $9° < m \leq 15°$ for grazing land, where $m = slope$.
3. Using a combination of the two classification maps. Slope can be chosen to either add to or subtract from the user supplied map, or alternatively, the user supplied map can either add to or subtract from the slope map. This combination of the two can be very useful if, for example, a user wishes to use a soil classification map as the primary indication of landuse suitability, but refine that map by taking out the land they consider too steep for use. In this case the program generated slope masks would be subtracted from the user supplied (soil) classification map.

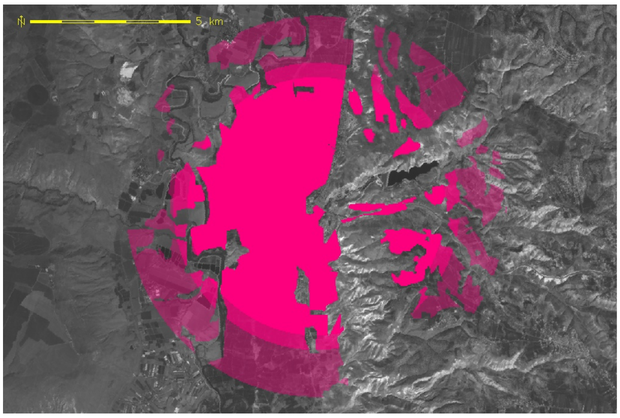

Figure 13: *Results which identified the suitable land surrounding Shuna using Euclidean method. The different shades represent different settlement populations.*

Finding the land

From a GIS point of view, one of the greatest challenges of this project was developing a method for finding the outer extent (or boundary), within which the combined area of suitable land satisfies the target area. The usable land surrounding a settlement is almost certainly not going to be contiguous, but rather comprised of multiple, irregularly shaped polygons. A further complication is the fact that some of the irregularly shaped polygons may be bisected one or more times by the 'boundary line'.

In order to find the suitable land required to produce enough food to sustain the settlement that is in closest proximity, a conditional loop is used which defines the outer extent of the catchment area, and then calculates the area of suitable land contained within it. This process is identical for all analysis methods. The earliest versions of LA started at the closest point to the site that could potentially solve the problem [4], and then moved steadily outwards until the area target was found. The amount to move outward in each step was provided by the user, and might have been a value like 30 (which in the case of walking distance meant 30 seconds, on a cost surface of 20,000. This would mean that potentially, there would have to be $\frac{20,000}{30}$ or nearly 7000 iterations!) The basic steps involved were:

1. Set the initial boundary at which to start the analysis
2. Calculate the area of suitable land found within this boundary

[4]The closest point, or minimum radius, is a perfect circle equal in area to the target.

3. If the area of land required has been satisfied, write the results to a new file for that item and exit the loop

4. Increase the value of the analysis boundary

5. Repeat the loop (starting at Step 2)

This method proved extremely time consuming; If even 3,500 loops, which is about half of the cost surface map, was required, and each loop took as little as 45 seconds, the computation time was nearly 44 hours. Multiply this, then, by the number of individual crops and animals in the model and the run time suddenly needs to be expressed in days or weeks. To increase the efficiency, a modified binary search is now used. This involved a somewhat different approach. Instead of using a step amount, a percentage is used. This percentage value is called the *Precision*.

The area of land deemed by LA as equalling the current area target gets changed into a target range $\pm$ the precision value multiplied by the target area. If a value of 5% is entered, and the area target is 100 hectares, LA accepts $100 \pm (\frac{100 \cdot 5\%}{2})$ (which is 97.5 to 102.5 hectares) as the target area.

The loop uses three terms, *CurrentMidValue* *FirstValue* and *LastValue*. At the beginning of the process, $FirstValue = 0$ and $LastValue = 18,000$ which coincides with the full extent of the cost surface. *CurrentMidValue* is calculated within the loop. The loop works like this:

1. Set the analysis boundary: $CurrentMidValue = \frac{FirstValue + LastValue}{2}$.

2. Calculate the area of suitable land found within the boundary whose outermost boundary is *CurrentMidValue*

3. If the contained area falls within the target range, write the results to a new file and exit the loop

4. If the contained area is more than the maximum value in the target range, set a halfway between *FirstValue* and *CurrentMidValue*. This is done by making $LastValue = CurrentMidValue$ and then returning back to step number one. (Note *FirstValue* remains unchanged.)

5. If the contained area is less than the minimum value in the target range, set a halfway between *LastValue* and *CurrentMidValue*. This is done by making $FirstValue = CurrentMidValue$ and then returning back to step number one. (Note *LastValue* remains unchanged.)

By using this method, the *maximum* number of steps in the loop is 17. This method of searching for the area targets made a huge difference in LA's speed. A typical 'run' on a decent computer system is now $\approx$ 2 to 3 minutes, compared days and weeks using the original method. This allows a user to now examine many different variations of an entire model quickly and easily, even on an average computer system.

Finally, at the end of the process, LA produces maps which clearly show which land people in the settlement were likely to have been engaged with, and for what purpose they were using it (Figure 14).

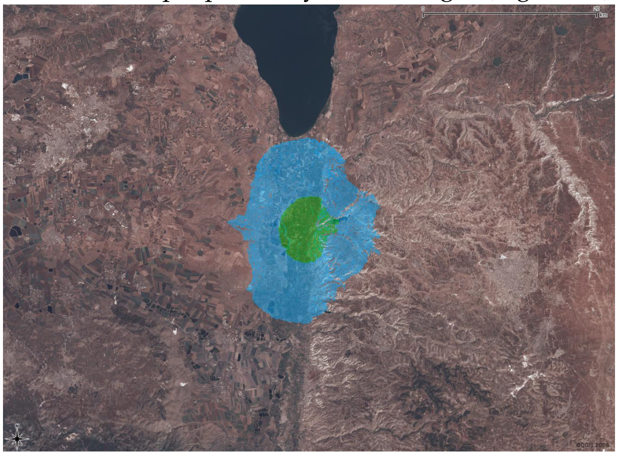

Figure 14: *Sample results for Shuna, Late Early Bronze Age, Population 3000, 90% plant and 10% meat. Green is for cropland, blue grazing land. Walking Time was used to create the cost surface, and slope was used for mask generation.*

Future development

LA is still in the early stages of its development and many improvements to usability and application capabilities are planned. That said, the application is already capable of producing useful results (though more testing is still needed) in a more flexible, user friendly and efficient manner than the original BASH prototype.

There are many routes that LA can take from this point with respect to it's future development; it can continue on as a standalone application, or turn into a plugin for another application like openModeller or QGIS. Before these decisions are made, however, the features in the current version must be finalised and implemented. Some features which are currently in the planning phase are network analysis for inter-site relationships, experiment settings, where the model can be set to run a given number of times using different input variables, and report generation complete with graphs and maps.

The network analysis feature will look at all contemporaneous sites in a given area, and examine production potential. If a site can potentially produce excess meat, but falls short in cropland, it will look to neighboring sites to see if they can make up the difference. If there is a potential for trade or supplementation, the most efficient walking routes can then be found using r.drain on a cost surface generated with r.walk. This could potentially show the likely pathways between sites, as well as how intensively used they might have been. Taking this further, one might look for places where these routes merge, or cross, which might be an indicator for a potential archaeological site which has yet to be discovered.

The current version of LA requires that every scenario be modelled manually and separately. For example, one might wish to look at how adjusting the yield of crops would affect the land requirements to simulate drought years. One might also want to compare the results of different dietary proportions of meat content to plant content. With the experiment module, it will be possible to have the software automatically cycle through all of these different scenarios automatically.

Drawing much on the work done in openModeller, there is also the hope that it will be possible to have LA compile presentation quality reports, complete with spreadsheets and graphs. This will be a great time saving feature. In addition, this will provide a consistency that will make it much easier to systematically compare results with other users.

Anyone interested in knowing more about this project, or better yet, in contributing to it, please don't hesitate in contacting us.

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New Publications

the title of the publication

Herborg et al. (2003)

the abstract/description goes here

the title of the next publication

Lurz et al. (2001)

the abstract/description goes here

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