Predictive Modelling: a Case Study of Agricultural Terraces at Monte Pallano (Abruzzo, Italy)

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Abstract:
This paper describes the development and testing of a GIS predictive model as part of the Sangro Valley Project's 2010 survey of agricultural terracing on Monte Pallano in Abruzzo, Italy. The survey was designed to assess the spatial distribution of terracing and to examine major patterns of terrace form, construction style, and preservation. Using the locations of previously recorded terraces, the survey modelled optimal areas for terracing based on cultural and environmental factors. New terrace data collected by the survey was used to refine the model. The resultant model indicated that the key factors determining terrace placement were different than originally theorized. This study will be continued in the 2011 field season with extended survey and soil sampling of selected terraces. Delineating the history and extent of agricultural terracing on Monte Pallano is essential for understanding the long-term dynamics of settlement and land use in this region.

Key Words: *Predictive Modelling, GIS, Agricultural Terracing*

Introduction

In 2010, the Sangro Valley Project began a survey of abandoned agricultural terraces on Monte Pallano, a limestone ridge dominating the middle Sangro River valley in the Abruzzo region of Italy (Fig. 1). The Sangro Valley Project is devoted to investigating and characterizing the long-term patterns and dynamics of human settlement and land use in the context of a Mediterranean river valley system (http://www.sangro.org/). Its research over the past 16 years has provided evidence – through surface surveys and excavations of domestic sites on and around Monte Pallano – for the area's habitation in the Iron Age through the Roman periods (7th century BC – 3rd century AD) (Fig. 2). Ancient and modern settlements in the vicinity of Pallano tend to cluster at 500 to 700m in elevation, and important ancient public and ritual sites have been discovered on the summit of the ridge. The 2010 Terrace Survey was designed to provide additional contextual information for long-term land use in the area by assessing the spatial distribution of agricultural terraces on the unsurveyed slopes of Monte Pallano between 700 and 1000m in elevation, between the ring of modern settlements and the archaeological sites on the summit. The survey recorded the locations of agricultural terraces on Monte Pallano and examined the patterns of individual terrace form, construction style, and state of preservation. Central to this project was the development of a GIS predictive model to analyse the cultural and environmental factors that might influence the spatial distribution of agricultural terraces.

Figure 1. Location in Italy of the Abruzzo region and Monte Pallano.

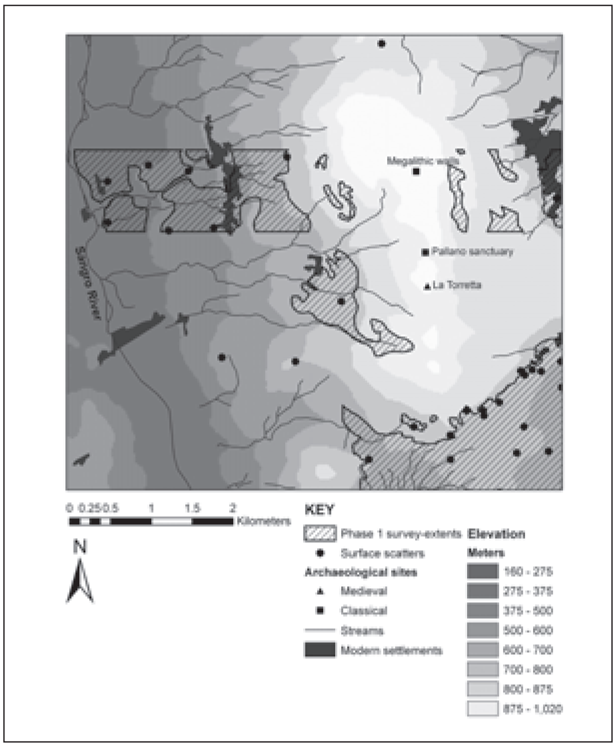

Figure 2. Monte Pallano and environs, with major archaeological sites and the finds of the Sangro Valley Project Phase 1 surface survey (1994-1998).

Background: Mediterranean Agricultural Terracing

Agricultural terracing is a land management strategy that is common to mountainous regions throughout the world (Douglas et al. 1996; Dunning and Beach 1994; Inbar and Llerena 2000; Nickel 1982; Sandor et al. 1990, Sutton 1984; Treacy and Denevan 1994). Terrace walls serve to create cultivatable land on steep slopes by preventing soil erosion, improving soil depth and root penetration for crops, collecting rainwater runoff, and by making use of field stones which would otherwise interfere with cultivation (Grove and Rackham 2001, 111; Rackham and Moody 1992, 124; Sandor et al. 1990, 74). Terraces can be used to grow virtually any crop; they are usually associated with vines, olives, wheat, legumes, corn, and potatoes (Table 1). Many terraced slopes in Mediterranean countries are no longer cultivated – a symptom of the decline in agriculture which has taken place in the region since the beginning of the 20th century (Grove and Rackham 2001, 91-92, 107; Rackham and Moody 1992, 126). Terracing is a significant form of landscape modification in the Mediterranean, but one that has only recently become an object of serious study by archaeologists.

There is much debate among Mediterranean landscape archaeologists as to whether or not terracing was practised in antiquity (cf. Grove and Rackham 2001, 112-113, 117; Foxhall 1996, 44-67; Price and Nixon 2005, 2-5). Terraces are notoriously difficult to date, as they can be used continuously for hundreds of years if properly maintained, and it is plausible that some Mediterranean terrace systems could be thousands of years old.

The study area of the Sangro Valley Project (hereafter abbreviated SVP) is well suited for

		Settlement proximity (m)	**Road/path proximity (m)**	**Spring proximity (m)**	**Stream proximity (m)**	**Flow accumulation**	**Slope (degrees)**	**Insolation (Watt hrs/ m^2)**
Phase 1 and 2009 survey terraces:	Minimum	0	10	70.71	20	0	4.26	953,930
criteria values at points	Maximum	610.33	89.44	1050	296.98	55	12.55	1,090,400
(total number of terrace points = 17)	Mean	292.72	37.07	553.96	178.59	12.88	8.55	1,017,400
	St. Dev.	179.53	21.2	309.46	96.44	16.65	2.56	51,981
	1st Quart.	143.57	20.59	360.36	90	3	6.26	970,760
	Median	275	33.03	507.23	218.4	5	9.25	999,700
	3rd Quart.	442.94	39.94	862.5	286.36	20.75	10.37	1,070,900
Reclassified values:	1 (more suitable)	0-293	0-37	0-554	0-179	13-10,276	4-52.5	1,017,400-1,160,264
suitability for terracing	2 (less suitable)	293-14,890	37-780	554-5580	179-1380	0-13	0-4	601,450-1,017,400
Percent weight in overlay	(Fig. 4a)	5%	5%	18%	18%	18%	18%	18%
	(Fig. 4b)	25%	25%	10%	10%	10%	10%	10%
2010 survey terraces:	Minimum	0	0	64.771	0	0	2.25	970,350
criteria values at points	Maximum	836.27	201.44	1101.1	739.62	1278	29.96	1,111,800
(total number of terrace points = 215)	Mean	443.6	70.18	483.96	317.88	17.82	12.14	1,061,700
	St. Dev.	161.28	55.23	251.19	252.78	106.92	5.06	33,378
	1st Quart.	373.99	22.38	267.06	90.32	1	8.92	1,048,200
	Median	476.75	63.3	377.67	171.96	3	11.87	1,070,400
	3rd Quart.	545.18	111.91	660.53	579.29	10	15.01	1,083,300
Reclassified values:	1 (highest)	282-605	15-125	233-735	65-571	0-18	7-17	1,028,322-1,095,078
probability of terracing	2	121-282	0-15	0-233	0-65	18-232	17-22	1,095,078-1,128,456
	3	605-766	125-180	735-986	571-823	232-339	2-7	994,944-1,028,322
	4	0-121	180-236	986-1,237	823-1,076	339-445	22-53	1,128,456-1,160,264
	5 (lowest)	766-14,890	236-780	1,237-5,579	1,076-1,377	445-10,276	0-2	601,450-994,944
Percent weight in overlay	(Fig. 6a)	5%	5%	18%	18%	18%	18%	18%
	(Fig. 6b)	25%	25%	10%	10%	10%	10%	10%

Table 1. Table showing values of environmental variables at terrace points recorded in Phase 1/2009 surveys and 2010 terrace survey, reclassified values derived from each data, and percent weight given to each variable in two weighted overlay analyses.

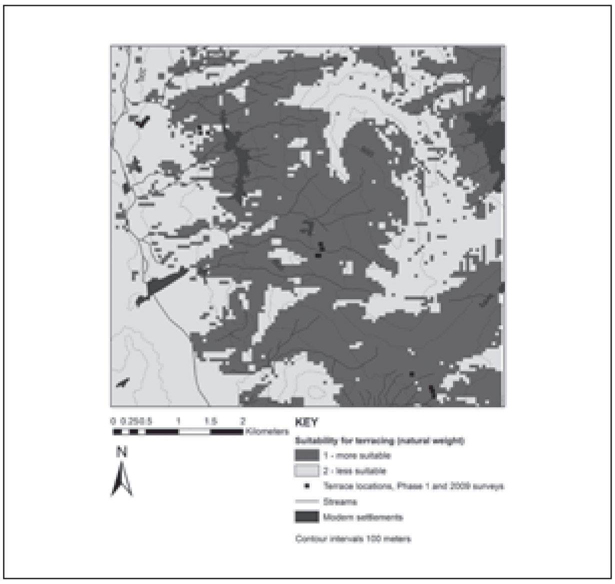

Figure 3a. Preliminary predictive model, with weight given to natural features (spring proximity, stream proximity, flow accumulation, slope, and sunlight.) Shaded areas are those deemed most likely to be terraced according to this model.

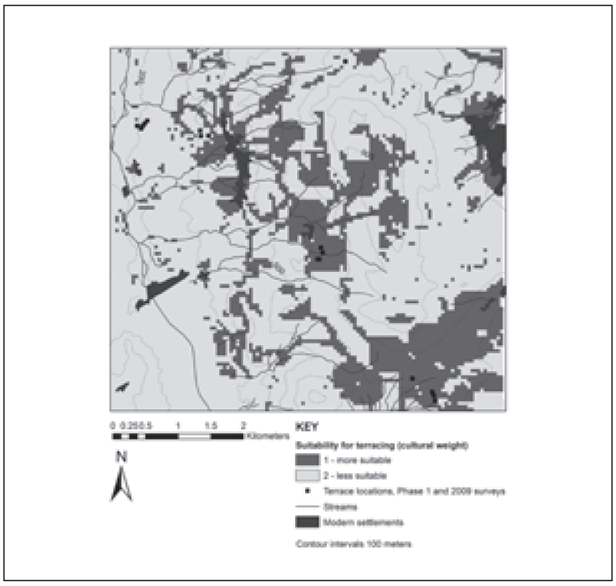

Figure 3b. A preliminary predictive model, with weight given to cultural features (proximity to roads, proximity to archaeological sites and settlements.) Shaded areas are those deemed most likely to be terraced according to this model.

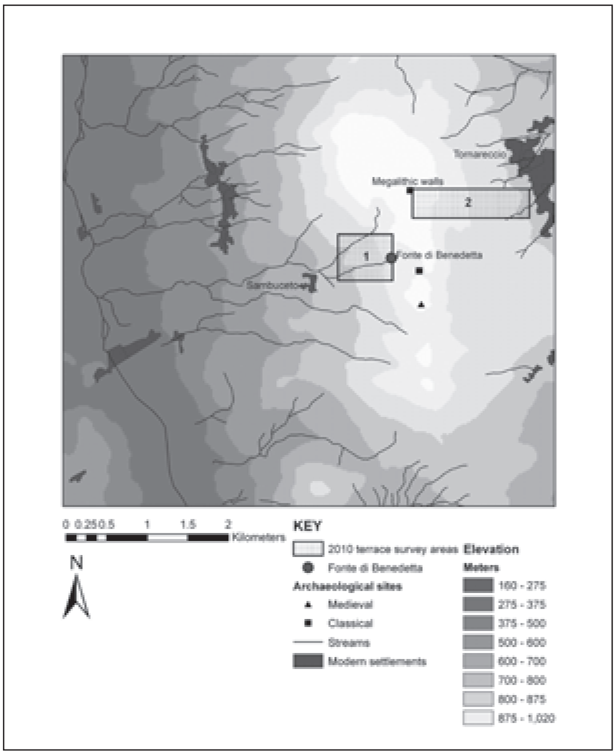

Figure 4. Areas of Monte Pallano selected for 2010 terrace survey.

an investigation of Mediterranean agricultural terracing. Excavations at Acquachiara, on the southern face of Monte Pallano, revealed multiple phases of terracing associated with an agricultural processing site dating to the sixth century BC (Bispham and Kane 2006; Mather 2007; Thomas et al. 2005). Although the upper flanks of Monte Pallano are now mostly covered in dense forest, much of this area was open and under cultivation with the aid of terracing as recently as sixty years ago (Nicola Totaro, pers. comm. 14 July 2010). Previous SVP surveys had noted the presence of terracing on these forested upper slopes of the mountain but these features had never been systematically mapped or studied. Yet terraces are archaeological features that, unlike potsherds, can be detected even under heavy vegetation. Terraces can therefore be especially useful in reconstructing settlement and land use patterns in forested areas not amenable to conventional field-walking. The intent of the 2010 season terrace survey was to explore the previously unsurveyed upper slopes of Monte

Pallano and to create a more detailed record of the archaeological features in this area.

GIS Predictive Model

Prior to beginning fieldwork in July 2010, the survey applied ESRI software to create a GIS map of Monte Pallano and the surrounding area. The GIS included aerial photos, topographic maps, cultural layers (roads, political boundaries, settlements and known archaeological sites) and environmental layers (digital elevation models, slope, aspect, sunlight, water sources, land use, etc.) A handful of terrace features had been recorded, with geographic coordinates, by previous SVP surface surveys. These points were layered into the GIS and used to develop a predictive model of those areas of Monte Pallano with environmental conditions most suitable for agricultural terracing. This model consisted of a weighted overlay analysis of seven criteria that were hypothesized to be influential in determining the placement of a terraced farm field:

1. Proximity to archaeological sites and settlements (including surface scatters),
2. Proximity to roads and paths,
3. Proximity to springs,
4. Proximity to streams,
5. Flow accumulation (a raster model of alluviation, measuring the accumulated weight of all cells flowing into downslope cells in a digital elevation model),
6. Slope,
7. Insolation during the growing season (modelled as April-October).

The modellers assumed that terraces would favour steeper slopes, that they would likely be concentrated close to villages and other major structures (Bevan et al. 2003, 220), that they would favour proximity to roads for ease of access, and that they would favour proximity to sources of water; terraces might be preferably built near drainage areas in order to catch more run-off, and the existence of cross-channel terraces built over streams is well-documented in other regions of the world; terraces would presumably also favour southerly aspects with high levels of insolation. Each of the seven variables was represented by a raster layer. These rasters were reclassified into 2 new value classes, 1 representing values more suitable, and 2 representing values less suitable for terracing. Optimal values for each variable were determined based on the average values at the recorded terrace points. For proximity rasters, this meant optimal distance values between the average and 0; optimal values for flow accumulation, slope, and insolation were modelled as the average to the highest possible value for the raster. The reclassified variables were then each given a percent weight and combined using a weighted overlay into a new raster with values of 1 and 2, where 1 indicates higher suitability for terracing and 2 indicates lower suitability. Each new raster cell is a sum of the seven input variables multiplied by their percent weight:

new cell = (variable 1 • %) + (variable 2 • %) + (variable 3 •) + ... + (variable 7 • %)

Multiple versions of the weighted overlay were performed, with different percent weights given, to test how the model changed when greater weight was given to particular criteria. The values used in reclassifying the variables and the weights given in two overlays are shown in the table in Table 1. The resulting predictive models are shown in figures 3a and 3b.

The resulting models appeared rudimentary, limited by the resolution of the input rasters and by the small number and uncertain positional accuracy of the previously recorded terrace coordinates. The model nevertheless provided a starting point for selecting particular areas to survey in detail. We chose two survey areas, one on the west side of the mountain running between the Fonte di Benedetta and the modern

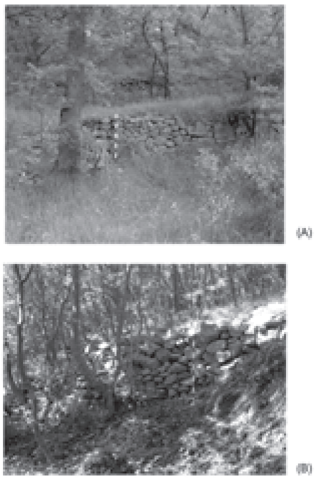

Figure 5a. (Upper image) Terrace type A. (Lower image) Terrace type B.

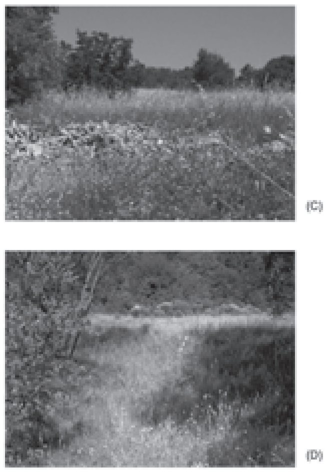

Figure 5b. (Upper image) Terrace type C. (Lower image) Terrace type D.

village of Sambuceto, and another on the east side running from the Iron Age megalithic walls to the edge of the modern village of Tornareccio (Fig 3). These two zones differ notably in topography: the Benedetta-Sambuceto zone (zone 1) is a steeper face of the mountain and is cut through by two narrow gorges; The walls-Tornareccio zone (zone 2) consists of a series of steep slopes alternating with wide, flat ridges. Both survey zones contained areas that the model predicted to be favourable and areas predicted to be unfavourable for terracing. The new data to be collected in each transect would therefore enable a test of the model.

Data Collection

The dense vegetation and variable terrain of Monte Pallano required a flexible, reconnaissance style of survey. The survey team followed the numerous forest trails and abandoned farm roads to explore the areas selected for survey, generally moving from the top of Monte Pallano down towards the modern settlement. The location of all terraces encountered was recorded in UTM coordinates using a Trimble GeoXT handheld GPS receiver. The surveyors recorded the length, height, and width (where visible) of each terrace wall, dimensions of several sample wall stones, and made observations on the surrounding vegetation, slope and orientation of the hill, construction style of the terrace, its degree of erosion and lichenization, and the presence of any stone piles, field boundary walls, paths, or other terraces in the vicinity. This information was recorded on paper survey forms in the field, and entered into an attribute table attached to the terrace layer in the GIS. The survey methodology was inevitably biased towards recording the terraces closest to the navigable roads and paths. Many other areas were inaccessible due to terrain and vegetation.

Survey Findings

In two weeks of fieldwork, the survey recorded over one hundred individual terraces in both of the survey zones and a handful of terraces in locations outside the two main transects. Most of the observed terraces have stone-walled embankments, with very rough-cut masonry and no use of mortar. The survey classified the terraces into four categories, based on masonry (Figs. 5a and 5b):

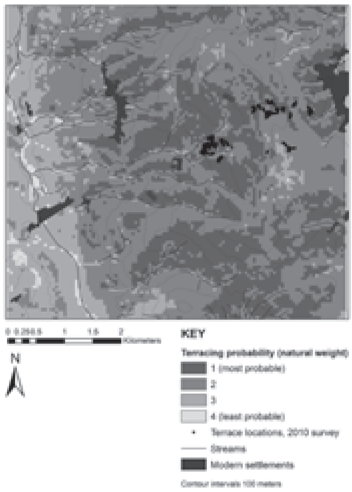

Figure 6a. Revised predictive model, with weight given to natural features (spring proximity, stream proximity, flow accumulation, slope, and sunlight.) Probability of terracing is represented by a 1-4 scale, with value of 1 indicating highest probability of terracing, value of 4 indicating lowest probability of terracing.

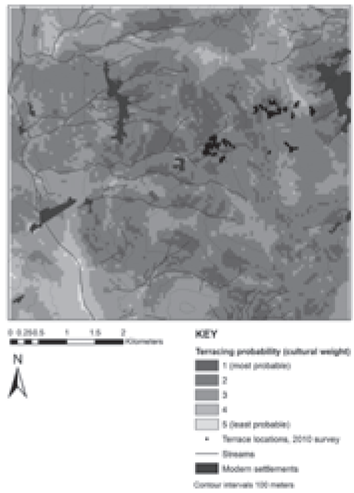

Figure 6b. Revised predictive model, with weight given to cultural features (proximity to roads, proximity to archaeological sites and settlements.) Probability of terracing is represented by a 1-5 scale, with value of 1 indicating highest probability of terracing, value of 5 indicating lowest probability of terracing.

- Type A) Coursed and faced wall stones.
- Type B) Coursed/semi-coursed, but unfaced wall stones.
- Type C) Piled stones, without any coursing or facing.
- Type D) No stone wall of any kind, just an artificial break in slope, which may or may not be lined with trees or hedges. (*lynchet* or *ciglioni*).

Many of the Type D terraces in the survey areas displayed small segments of stone walling or had stones scattered along the break in slope, suggesting the presence of a stone wall that had eroded away or become buried by sediment in vegetation. These terraces may therefore be of comparatively early date.

Some notable differences in the style and spatial patterning of terraces were found between the east-side and west-side transects. The terraces on the west flank of Monte Pallano tend to be in much closer proximity to each other than those on the east. Those on the western flank also more frequently form parallel series, creating networks of terraced fields, whereas terraces on the east side often appear to be less spatially structured. The eastern flank exhibits a greater frequency of non-terrace structures that indicate agricultural activity: boundary walls, piles of field stones, and collapsed stone huts. These features are to be found in the western tract as well, but they are not predominant. The differences in construction style and spatial distribution of terraces between the west and east sides of Monte Pallano could indicate that the terraces were used for different purposes, were perhaps constructed during different time periods, and possibly reflect different types of organization of the agricultural systems.

Additional reconnaissance work was undertaken at lower elevations in the valley to ground-truth the terraces that had been recorded by the Phase 1 and 2009 terraces. Many of these terraces could not be relocated. those that were relocated proved to be modern,

Categories	Natural weight	Cultural weight
1 (more suitable)	153 terrace points	45 terrace points
2 (less suitable)	63 terrace points	171 terrace points

Table 2. Revised Predictive Model.

Categories	Natural weight	Cultural weight
1	101 terrace points	64 terrace points
2	115 terrace points	144 terrace points
3	0 terrace points	8 terrace points
4	0 terrace points	0 terrace points
5	N/A	0 terrace points

Table 3. Revised Predictive Model.

unwalled terraces of a different type to those found at higher elevations on Monte Pallano. These terraces were not included in the new data set.

Revised Predictive Model

The new set of terrace data was used to revise the GIS model. New terrace location points corresponding to every 10m of terrace wall mapped by the survey were layered into the GIS. The values of the seven environmental criteria, along with the values of the predictive models, were extracted to these points, and their spread compared to the values in the early predictive models. The model giving weight to natural criteria was the more accurate, encompassing 71.8% of the newly recorded terrace points (Table 2).

Neither of the preliminary models encompassed the terraces in their entirety, nor did they account for the variability with which different environmental criteria might combine to influence terrace placement. In order to create a more nuanced model that reflected a spectrum of terracing probability, the seven variables were reclassified once again into five new value classes, rather than two. The new classes were defined based on the mean and standard deviations of the variables at the new terrace locations. Values within one standard deviation above and below the mean were given a value of 1, representing high probability of terracing. The 1st and 3rd quartiles of the terrace points were generally encompassed by this category, so it was held to be reasonably accurate. Two standard deviations above and below the mean defined the limits of classes 2 and 3, and classes 4 and 5 were defined by the maximum and minimum possible values of the rasters. As before, it was assumed that lower values for proximity rasters were preferable and higher values for slope and insolation. In the case of flow accumulation, the data seemed to show that areas of low accumulation were more heavily terraced than areas of high accumulation, and the reclassification parameters were made to reflect this. The data spread for the new terrace locations recorded by the 2010 survey, with the reclassified values of the variables, are shown in figure 3. These reclassified variables were combined in a weighted overlay in the same manner as described above and using the same two sets of weights. When weight was given to natural variables (Fig. 6a), the resulting model yielded a 1-4 spectrum, with 1 representing areas of highest probability for terracing and 4 representing areas of lowest probability. Weight given to cultural features (Fig. 6b) yielded a model with a 1-5 spectrum, where 1 represents areas of highest terracing probability and 5 represents areas of lowest probability.

The new models greatly improved upon the earlier ones. When weight was given to natural criteria, all of the terrace points fell within the first two classes, and when weight was given to cultural criteria, only 8 points fell in the third class and the remainder fell in areas with values 1 or 2 (Table 3).

Overall, there is minimal difference visually between the two versions of the revised model. Neither contains the majority of the terrace points within highest probability category. Nor do they account for the frequent occurrence of stone-walled terraces on the upper slopes of Monte Pallano but the general absence of such terracing lower in the river valley. Some important variables determining the placement of terraces are probably missing from our GIS, and other variables may be less important than originally supposed. The terraces do not exhibit a distribution that favours proximity to springs, for example, indicating that they would have been watered primarily by rainwater and not by irrigation. Neither are terrace locations immediately adjacent to archaeological sites; instead they are most often between 300 and 600m away from settlement sites, suggesting that settlement zones and agricultural zones on Pallano may be distinct from each other. While many of the terraces do favour sunny hillsides, others exhibit northwestern and northeastern aspects, receiving less sunlight over the course of the year than more southerly aspects. The degree of the slopes upon which they are constructed are also surprisingly variable: many shallow slopes high up on Pallano are terraced, while many steeper slopes at lower elevations are left un-terraced, suggesting that bedrock and soil depth must be playing a key role.

Some potentially important GIS data are not currently included in the models, notably soil characteristics and surface geology, data which were not available to the project when the models were developed. Given the functions of agricultural terracing, these variables likely play a significant role in terrace placement (Bevan et al. 2003, 224, Grove and Rackham 2001, 110; Rackham and Moody 1990, 125). Much of the soil on the upper slopes of Monte Pallano is thin and rocky, and piles of scree formed from the fracturing limestone bedrock are frequent. The terraces on Monte Pallano all appear to be constructed of stones collected from the surrounding area. Terracing appears to be prompted as much by the desire to remove stones from the fields as much as the need to create a gentler slope on which to grow crops. Soil and the prevalence of stone building material may be the crucial factors for determining which slopes are terraced and which are not.

Conclusions and Future Work

During the 2011 season, the SVP plans to extend the survey to areas on the northern and southern flanks and the summit of Monte Pallano, where extensive terracing is visible in aerial photographs. The expanded terrace data set should allow the survey to improve the spatial model of terrace distribution, and to analyse in more detail the potentially significant distribution of stylistic differences. The project also plans to excavate selected terraces in order to obtain soil samples for micromorphological analysis that may provide information to help us date the terraces. Adding soil and geological data to the project's GIS database will greatly enhance spatial analysis, and is essential for fully understanding the patterns of land use in the region.

Although the current predictive model is limited in its accuracy, the process of developing the model was useful to this study in that it helped to determine which environmental factors were and were not important in determining the placement of agricultural terraces. The failure of slope, sunlight, hydrology, and cultural features to entirely account for the spatial distribution of the terraces in itself indicates that the most important environmental parameters are those that are missing from the model, namely soil and bedrock.

The continued study of terraces on the slopes of Monte Pallano will provide new evidence to complement previously obtained data from excavations in the area. Because they represent the exploitation of otherwise marginal land, the use and disuse of terraces can be a measure of population change, socio-economic pressures, and possibly cultural change as well. As a major form of landscape modification, understanding the distribution and purpose of terracing is an essential component of reconstructing settlement and land use on Monte Pallano through time.

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