Analecta Praehistorica Leidensia 28 / Interfacing the past : computer applications and quantitative methods in archaeology CAA95 Vol. I

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ANALECTA PRAEHISTORICA LEIDENSIA 28

PUBLICATIONS OF THE INSTITUTE OF PREHISTORY
UNIVERSITY OF LEIDEN

INTERFACING THE PAST

COMPUTER APPLICATIONS AND QUANTITATIVE METHODS IN ARCHAEOLOGY CAA95 VOL. I

EDITED BY
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UNIVERSITY OF LEIDEN 1996

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Estimating the age of stone artifacts using probabilities

1 Introduction

This article describes an application of the Bayesian approach to estimate the age of lithic artifacts collected by surface surveys in West Central Italy (fig. 1). Although the application refers to very specific circumstances and cannot be directly transferred to a different situation or region, the general procedure may be useful as a way to systematically pull together disparate information to assign materials to classes.

Figure 1. Location of study area.

2 The archaeological problem

The problem was to estimate the age of lithic artifacts collected on the surface of older land formations during archaeological surveys of the Agro Pontino (Voorrips *et al*. 1991), the Fondi Basin (Bietti *et al*. 1988), and the area around Cisterna (Attema 1993) in West Central Italy (fig. 2). Physical geographers from the University of Amsterdam, who mapped the soils in the area, established the relative ages and surface stability of various formations (Sevink *et al*. 1982: 1984). Subsequent research provided absolute dates for some of the older formations with stable surfaces (Hearty/Dai Pra 1986; De Wit *et al*. 1987), which is where Palaeolithic materials could be found coming up in the plough zone. On these stable surfaces one would not expect to find sites for excavation, but instead recover a portion of a fossil archaeological landscape in the form of a palimpsest of artifacts discarded over thousands and thousands of years.

Some of the stone artifacts collected could be assigned to tool types that are considered chronologically diagnostic in the region. These artifacts were used to date sets of aggregated fields, termed sites, in a very general way, i.e., Middle Palaeolithic, Early Upper Palaeolithic etc. This is a standard procedure for dealing with lithic scatters, at least in America (e.g. Bamforth 1986) and Northern Europe (e.g. Arts 1989). Information published about the coastal area north of the Agro Pontino, where surfaces are also rather stable, led us to believe that we, too, could identify changes in site distribution over time in this way. In working with the materials, however, it became apparent that this would not be possible.

As part of the survey project and fulfilment of requirements for his doctorate, Kamermans (1993) conducted a land evaluation study of the region using artifacts collected by the Agro Pontino survey. Basing himself on presence/absence of periods represented at sites, determined by the presence of chronologically diagnostic tools and cores in the region, as stated above, he found that all the apparent differences in land use throughout the Palaeolithic could be explained by intervening geological processes. Thus, he concluded that the region was regarded as a single unit, at least for resource exploitation, throughout the Palaeolithic.

In the course of my investigation of the Agro Pontino materials, I found that there seemed to be so many sites with more than one chronological component that it would be unlikely that we should discover any spatio-temporal differences using presence/absence of components at sites.

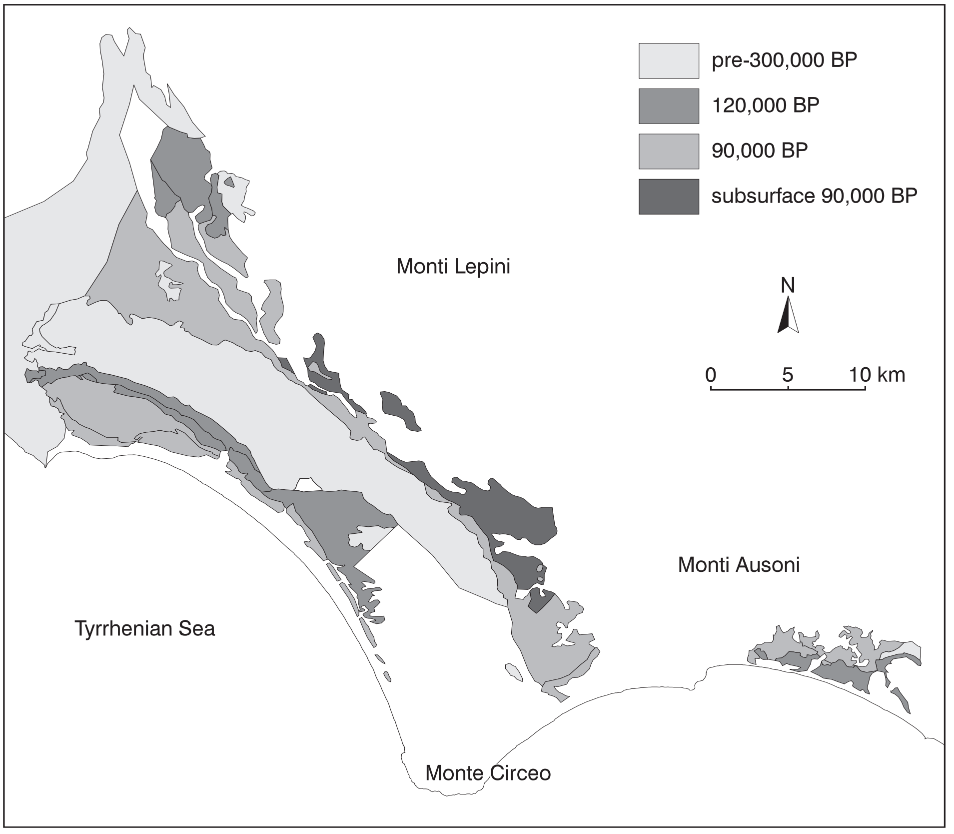

Figure 2. Distribution of older formations in the study area.

This aspect of the archaeological record of the Agro Pontino is brought into relief by comparing it with a more extensive sample along the Tyrrhenian coast. Mussi and Zampetti (1984-1987), two Italian researchers, had compiled the association of three Palaeolithic cultures — Mousterian, Aurignacian, and Epigravettian — represented in 49 sites along the coast from the Tevere to the Monte Circeo, including several on the Agro Pontino.

A set of chi-square tests on the co-occurrence or lack of it between these cultures shows that associations are due to chance (fig. 3), whereas the associations between the three cultures in sites on the Agro Pontino are all more than expected and the probability that this is due to chance is less than .05 in each case. Thus, the archaeology of the Agro Pontino appears to be quite different from the coastal area in general.

This situation meant that the evidence for differential use of the landscape within a cultural period and any changes through time would require an estimate of age at the level of the individual artifact rather than at the level of the site or location. To my knowledge, this had never been done with surface artifacts.

3 Expertise for estimating the age of artifacts

A recent article by Buck and Litton (1991) not only encouraged archaeologists to use Bayesian approaches, but provided a clear description about how to do so. Their idea that prior probabilities and additional data collected were forms of expertise was absolutely crucial. Bayes's theorem provides a way to pull together various kinds of expertise.

We did have or could collect various types of information, or forms of expertise, that might contribute to estimating artifact age.

3.1 Age of land surfaces and archaeological cultures in the region

The first type of information was the age of land surfaces in the area (fig. 2). Absolute dates for the latest tuff deposits are .338 Myr BP, stage 9-10 (?) (Fornaseri 1985) and for the Latina level are .54 Myr BP, stage 15 (De Wit *et al.* 1987). Minturno level deposits, including the beach ridge and associated aeolian sands, the coastal and inland lagoons, and the travertines, were dated to the last interglacial, *c.* .12 Myr BP, stage 5e, and Borgo Ermada level deposits, the beach ridge and coastal and inland lagoons,

Table 1. Approximate ages of geological formations on the Agro Pontino and archaeological cultures in West Central Italy.

Years BP	Formation	Archaeological culture
9,000		*Mesolithico*
12,000	Late Glacial aeolian sands	- - - - - - - - - - -
		Epigravettiano
20,000		- - - - - - - - - - -
		Gravettiano *Aurignaziano* *Uluzziano*
35,000		- - - - - - - - - - -
90,000	Borgo Ermada level	*Pontiniano*
120,000	Minturno level	- - - - - - - - - - -
		Musteriano *Acheuleano*
350,000	Colli Albani tuff	
550,000	Latina level	

were dated to about .09 Myr BP, stage 5b (Hearty/Dai Pra 1986).

Table 1 shows the temporal juxtaposition between the archaeological cultures and the age of land surfaces. Given the approximate ages of archaeological cultures, the Lower Palaeolithic *Acheuleano* and Middle Pleistocene Middle Palaeolithic *Musteriano* and *Pontiniano*, would be restricted to the tuff and Latina levels.

3.2 Typology and technology of lithic artifacts recovered from excavations

The second source of information was the artifacts recovered from major excavations in the area reported in the literature (table 2). Altogether, the information conveyed by the excavators constitutes a kind of collective expertise for the area. The completeness and detail of the reports, however, vary considerably, and, of course, the typologies used to describe the materials also vary according to whether the assemblages are Lower or Middle Palaeolithic or Upper Palaeolithic. In the more complete reports diverse kinds of information are offered. In addition to counts of typed tools are counts of different types of cores, counts of different types of debitage (flakes, blades, bladelets, burin spalls, etc.), counts or indices of Levallois flakes, and in some cases, counts of Pontinian scrapers (Middle Palaeolithic side scrapers with Quina retouch), which is a kind of 'stylistic' category.

As an archaeologist wanting to tap this expertise for my particular problem, I asked, 'given the contents of excavated sites, what is the probability that a particular artifact collected on the surface of the Agro Pontino comes from each of the 7 archaeological cultures?'.

Open air and cave sites along the Tyrrhenian coast, West Central Italy (N = 49)

Musteriano \ *Aurignaziano*	present	absent
present	17 (17.6)	4 (3.4)
absent	24 (23.4)	4 (4.6)

Chi-square = 0.19, df = 1
Approximate $p = .65$

Epigravettiano \ *Aurignaziano*	present	absent
present	13 (10.7)	12 (14.3)
absent	8 (10.3)	16 (13.7)

Chi-square = 1.76, df = 1
$p = .18$

Surface scatters on older formations in the Agro Pontino and Fondi Basin (N = 208)

Musteriano \ *Aurignaziano*	present	absent
present	68 (52.6)	82 (97.4)
absent	5 (20.4)	53 (37.6)

Chi-square = 24.7, df = 1
$p < .05$

Epigravettiano \ *Aurignaziano*	present	absent
present	59 (41.8)	60 (77.2)
absent	14 (31.2)	75 (57.8)

Chi-square = 25.61, df = 1
$p < .05$

Figure 3. Comparison between sample on the coast of West Central Italy as compiled by Mussi and Zampetti (1984-1987) and sample from surfaces of older formations on the Agro Pontino and Fondi Basin.

The first step in the application was to construct probabilities for tool and core types etc., from the excavation reports available. This was done in three steps:

1. The Middle and Upper Palaeolithic type lists (Bietti 1976-1977; Bordes 1961) were combined to create a single type list that could incorporate the more common types. The artifact illustrated in figure 4 will be used as an example. It is typologically and technologically an end scraper on a flake. All Middle Palaeolithic end scrapers, Bordes types 30 and 31, most of which are made on flakes, were put into the same category as Upper Palaeolithic end scrapers on flakes, Bietti type 3.
2. Then, for each archaeological culture, counts of tool types were summed across the sample for that culture and percentages calculated.
3. Then, two probability tables were constructed, which were made conditional on the age of the land surface (table 3). The first table, to be used for artifacts found on tuff soils and the Latina level, was made by summing the percentages for each type across all seven

Table 2. Archaeological cultures represented in excavated sites in West Central Italy (compiled from: Bietti 1976-1977, 1984a, 1984b; Kuhn 1990; Piperno/Biddittu 1978; Segre-Naldini 1984; Taschini 1967, 1979; Tozzi 1970; Vitagliano/Piperno 1990-1991; Zampetti/Mussi 1988).

Archaeological culture	Site	Absolute dating, BP
Mesolithico	Riparo Blanc	8,565 ± 80
Epigravettiano	Peschio Ranano	9,730 ± 150
Epigravettiano	Riparo Salvini	12,400 ± 170
	Palidoro	15,900 ± 150
Aurignaziano	Grotta Barbara	
	Fosselone, level 21	
Pontiniano	Grotta Breuil	36.6 ± 2.7 (Kyr)
Must. denticulato	Fosselone, level 27	
Pontiniano	Grotta di San Agostino (levels 1 to 3)	54 ± 11 to 43 ± 9 (Kyr)
Pontiniano	Grotta Guattari (levels 1-5)	77.5 ± 9.5 to 54.2 ± 4.1 (Kyr)
Pontiniano	Grotta della Cava	
Pontiniano	Grotta dei Moscerini (levels 39-25)	96 ± 1 to 79 (Kyr)
Pontiniano	Monte delle Gioie	
Pontiniano	Sedia del Diavola	
Musteriano	Torre-in-Pietra, level d	
Acheuleano	Torre-in-Pietra, level m	

Table 3. Prior probabilities that an end scraper on flake is associated with different archaeological cultures (based on 103 end scrapers on flakes reported in the literature).

Archaeological culture	If found on Latina level or tuff:	If found on Minturno or Borgo Ermada level:
Acheuleano	.11	-
Middle Pleistocene *Musteriano, Pontiniano*	.04	-
early Upper Pleistocene *Pontiniano*	.03	.04
middle Upper Pleistocene *Pontiniano*	.08	.09
Aurignaziano	.30	.35
Epigravettiano	.03	.04
Mesolithico	.41	.48

archaeological cultures and dividing each percentage by the sum to give the probabilities. The second table, to be used for artifacts found on the surfaces of other formations was constructed the same way, but only five of the archaeological cultures were used.

With this information, prior probabilities were assigned to all survey artifacts that could be put in one of the listed classes conditional upon the age of the land surface where they were found. The end scraper in figure 4 was found on soils in travertines, which developed during the Last

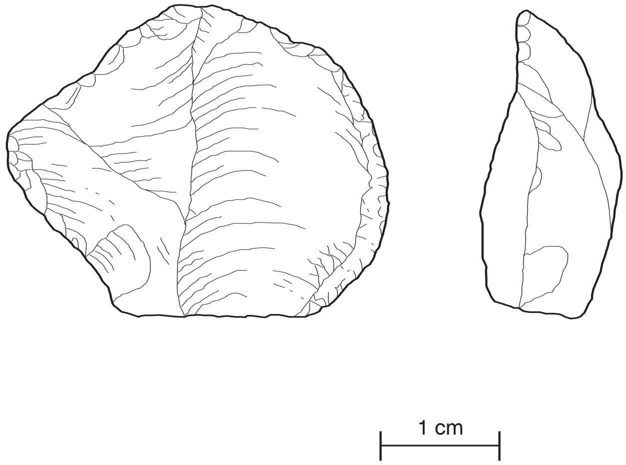

Figure 4. An end scraper on flake collected on travertine soils in the Agro Pontino.

Interglacial, in the same period as the Minturno level, *c*. 120,000 BP. Thus, the prior probabilities for it are found in the second probability table in table 3.

3.3 Technological attributes of lithic artifacts

The third source of potential information was technological change in lithic manufacture. Lithic specialists (e.g. Cotterell/Kamminga 1987; Crabtree 1972b; Faulkner 1973; Parry 1987) have shown that changes in such things as core platform preparation, flake profiles, flaking angles, types of fracture etc., can reflect changing techniques and tools used for lithic manufacture, which would certainly have occurred over the long period of time represented in this region. There was also reason to suspect that approaches to flaking the local raw materials changed during the Middle Palaeolithic in this region (Kuhn 1990, 1990-1991).

After selecting variables potentially relevant in a technological sense from publications by lithics specialists, I collected the data from about 900 flakes and 400 cores from four excavated collections housed in Rome. These collections were Grotta Guattari, dated from about .78 through .50 Kyr BP, level 3 of Grotta Breuil, dated to about .36 Kyr BP (both in Schwarcz *et al*. 1990-1991), part of the Aurignacian in Riparo Salvini and part of level 21 Grotta dei Fossellone (Blanc/Segre 1953; not dated radiometrically) and the *in situ* portions of Riparo Salvini (collected by A. Bietti; not dated radiometrically), dated to about 12,400 BP (Avellino *et al*. 1989). Probability tables were constructed using the chronologically significant technological variables or combinations of them that emerged from the analysis of the collections. The probabilities were derived directly from the data itself or from models that fit the data.

Unfortunately, it was not possible to study samples from all seven archaeological cultures, and it was necessary to collapse categories to middle Middle Palaeolithic and earlier, late Middle Palaeolithic, Early Upper Palaeolithic, and Late Upper Palaeolithic and later (table 4). The probabilities for tool and core types were recalculated to fit these four temporal categories. If samples from the other cultures — i.e. Lower Palaeolithic, Middle Pleistocene Middle Palaeolithic, and Mesolithic — are analysed technologically, then this will no longer be necessary.

The next step in the application was to calculate posterior probabilities for all items that had acquired a prior probability in the first step and that could be coded for the relevant technological variables listed in the technological probability tables. In doing so, it was assumed that these two sets of probabilities were independent of each other. This was necessary because I had no information about the relationship between tool types and the technological variables.

The end scraper on a flake found on soils developed in Last Interglacial travertines (fig. 4) has adjusted prior probabilities for four archaeological temporal categories as shown in table 5. Technologically, this artifact is a conchoidal tertiary flake with a smooth prepared platform, with dorsal flaking oblique to the direction from which the flake was struck, and with no ventral features, i.e. an eraillure scar or fissures, and no signs of abrasion adjacent to the butt on the dorsal side. The probabilities for a flake with these characteristics occurring per temporal category provide additional information. The posterior probabilities are calculated using Bayes's Theorem. So, the end scraper, which has prior probabilities in favour of Late Upper Palaeolithic or later changes to probabilities in favor of Early Upper Palaeolithic.

All other artifacts with technological attributes that were chronologically significant according to the analysis of excavated materials and had no prior probabilities were assigned prior probabilities on the basis of these attributes or combinations of them.

3.4 Patina of flint artifacts dependent on age, flint texture, and soil parent materials

The fourth and last source of information about age of surface artifacts in the Agro Pontino region was degree of patination. That the glossy patina on many of the artifacts collected by the Agro Pontino survey might be related to age of artifacts was suggested by Dick Stapert of the University of Groningen when he first saw them. So that this might be investigated, all artifacts were coded by comparing them with four items showing different categories of glossy patina — none, slight, medium, and heavy. Theoretically, glossy patination develops as

Table 4. Probabilities that an end scraper on flake comes from four temporal categories.

Archaeological culture	Original probability	Temporal category	Adjusted probability
if found on Latina level or tuff:			
Acheuleano	.11	middle Middle Palaeolithic or earlier	
Middle Pleistocene	.04		
Must. & Pont.			.18
early Upper Pleistocene	.03		
Pontiniano			
middle Upper Pleistocene *Pontiniano*	.08	late Middle Palaeolithic	.08
Aurignaziano	.30	Early Upper Palaeolithic	.30
Epigravettiano	.03	Late Upper Paleolithic or later	
Mesolithico	.41		.44
if found on Minturno or Borgo Ermada levels:			
early Upper Pleistocene *Pontiniano*	.04	middle Middle Palaeolithic or earlier	.04
middle Upper Pleistocene *Pontiniano*	.09	late Middle Palaeolithic	.09
Aurignaziano	.35	Early Upper Palaeolithic	.35
Epigravettiano	.04	Late Upper Palaeolithic or later	
Mesolithico	.48		.52

Table 5. Effect of additional information about technological features for estimating the age of the end scraper on a tertiary flake (based on 348 tertiary flakes examined from excavated collections).

	prior probabilities	probabilities based on technical features	posterior probabilities
middle Middle Palaeolithic or earlier	.04	.11	.01
late Middle Palaeolithic	.09	.36	.13
Early Upper Palaeolithic	.35	.39	.55
late Upper Palaeolithic or later	.52	.15	.31

superficial projections of silica are dissolved by soil water and deposited in superficial depressions on the surface of a fracture of flint, creating a glassy appearance. Important properties of the soil that promote or hinder solution of silica are pH and temperature in conjunction with the amount of organic compounds and aluminum ions (Luedtke 1992; Rottländer 1975). A few years ago, a loglinear model was found incorporating degree of patination, three archaeological periods, and three different kinds of sediment showing that these variables were probably interrelated in our samples (Loving/Kamermans 1991).

In examining the materials, we had also noted that more coarsely grained flints seemed to have less patina. According to geologists, it is probable that differences in the texture of the fracture surface seen macroscopically is due to porosity and clustering of quartz crystals in the stone as well as texture and that these properties affect both rates of weathering and appearance (Luedtke 1992).

Artifacts that had acquired a .6 probability or more for one of the four temporal categories in the previous steps of the application were used to build new loglinear models predicting for degree of patination based on age, sediment,

Table 6. Probabilities derived from loglinear models predicting degree of patination from age, type of sediment and stone texture (based on 1417 artifacts collected by surface survey).

Materials found in soils developed in travertines, aeolian and littoral sands:	light patina			heavy patina		
	fine-grain	medium-grain	coarse-grain	fine-grain	medium-grain	coarse-grain
middle Middle Palaeolithic or earlier	.18	.23	.24	.29	.30	.31
late Middle Palaeolithic	.23	.24	.24	.27	.29	.29
Early Upper Palaeolithic	.17	.22	.24	.30	.32	.33
late Upper Palaeolithic or later	.42	.31	.27	.14	.08	.07

Table 7. Effect of additional information about patina and texture for estimating the age of the end scraper on flake example.

	prior probabilities based on tool or core type and technological features	probabilities based on patina and texture	posterior probabilities
middle Middle Palaeolithic or earlier	0.01	.30	.03
late Middle Palaeolithic	.13	.29	.19
Early Upper Palaeolithic	.55	.32	.75
late Upper Palaeolithic or later	.31	.08	.02

and texture. Incorporating texture in the models showed that it had more effect than the type of sediment and as much effect as age of the artifact on the degree of patination; furthermore, texture of raw material is associated with the age of the artifact, so we even learned something we had not known before. After selecting the models that best fit the data, probability tables for age of artifacts given, degree of patination, texture, and type of sediment on which they were found were constructed from the models. There are two models. One for soils developed in tuff and lagoonal clays and a second one for all other soils (table 6).

The end scraper on a flake (fig. 4) was found on soils developed in travertine. It has a medium texture out of three categories — fine, medium, coarse — and a heavy degree of patination out of two categories — light and heavy. Based on these properties alone, it would have about equal probabilities of coming from one of the first three categories, but a very low probability of coming from the fourth category — Late Upper Palaeolithic or later.

The next step in the application, then, was to calculate posterior probabilities for all artifacts with prior probabilities that had not been used for analysis to construct the last set of probability tables. Again, it was assumed that information for prior probabilities was independent of the added information. The additional information for the end scraper on flake gives it a much higher probability of dating to the Early Upper Palaeolithic (table 7).

All other flint artifacts collected by the survey from older surfaces that had not acquired probabilitistic estimates of age in the previous steps were assigned probabilities deriving from each of the temporal categories using this last set of probabilities tables.

4 Computerized aspects of the application

Calculating posterior probabilities as other sources of information become available is an extremely tedious procedure. Thus, a small computer program was written by Albertus Voorrips (University of Amsterdam) that allowed probabilities to be typed in and then performed the necessary calculations. This made it easier to 'walk' a sample of artifacts through the estimation procedure to see how the application performed.

A schema was drawn up to order the decisions used in the application. The order was generally the same as presented in the preceding section, but was adjusted to accommodate certain logical and archaeological precedents. For example, artifacts used for developing the models for degree of patina retained the probabilities used before the analysis. Likewise, certain technical attributes, most of them metrical, restricted an artifact to fewer chronological categories.

The schema was the basis for Voorrips to write a computer program to route the approximately 9000 artifacts collected by the surveys through the decision pathways, identify the appropriate probability tables, do the necessary calculations, and write out the final probabilities.

5 Assignment of artifacts to temporal categories

The final step in the application was to assign individual artifacts to one of the four temporal categories on the basis of their final probabilities. Since I do not know a way to determine a significant departure from a uniform distribution, a value of .6 or more for any one category seemed reasonable to accept as a best estimate.[1] In this way, about 4000 artifacts, a little over 40%, were assigned to one of the four temporal categories. By collapsing temporally adjacent categories into General Middle Palaeolithic and General Upper Palaeolithic, an estimate of age could be made for an additional 10% of the artifacts.

6 Discussion

These results made it possible to use counts and densities, to correct for time by calculating discard rates, and thereby to begin to see some patterning in possible use of the area. Although the data are now more tractable than before, there are certain drawbacks to the application. For one, there is no independent means of checking the validity of the results. For another, many decisions were made to construct the probability tables, and other archaeologists might do it slightly differently, which would most probably alter the outcome. Just how 'stable' the results that I obtained are is a matter for future investigation incorporating information from other or new analyses in the probability tables.

The procedure is most suitable for situations where the certainty about assignment to a class is low. If prior probabilities for an artifact belonging to a class are low, they will remain low unless additional information assigns low probabilities for the other classes. If, on the other hand, probabilities for belonging to two or more classes are about equal, additional information incorporated into the procedure will either increase the certainty of assignment of an artifact to one of the classes or it will maintain the initial uncertainty, showing that for that case the additional information is irrelevant for assignment to a class.

Acknowledgements

I would like to thank Amilcare Bietti of the University of Rome and the members of the Istituto Italiano Paleontologia Umana for access to the excavated collections and the Fondi Basin survey materials housed in Rome. I am, as usual, indebted to my partner in life and work, Albertus Voorrips; without his contribution, I would be doing the calculations into the next century. Katarina Biró, Hungarian National Museum, critically reviewed the analysis on which the technological probabilities are based.

Most of the financial support for the Agro Pontino survey was provided by the Instituut voor Pre- en Protohistorische Archeologie, Universiteit van Amsterdam. Additional funding was provided by NWO (Nederlandse Organisatie voor Wetenschappelijk Onderzoek) grant nos. 280-152-024 and 280-152-033. The project would not have been possible without the cooperation of the Soprintendenze di Lazio and the Nederlands Instituut te Rome and the participation of many students from the Instituut voor Pre- en Protohistorische Archeologie, the Instituut voor Prehistorie Leiden, and the Università di Roma, who did most of the field walking for the survey.

Finally, in preparation for this article, I would like to thank Hans Kamermans and an anonymous reviewer for their comments, which helped to improve the article and correct some of my oversights.

note

1 Bob Laxton suggested that Monte Carlo techniques might be used to establish probabilities for various probabilities under different numbers of classes.

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