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THE AGRO PONTINO SURVEY PROJECT

Methods and preliminary results

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RANDOMIZING OUR WALKS: THE AGRO PONTINO SURVEY SAMPLING DESIGN

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SUMMARY

The Agro Pontino archaeological survey took place in three sampling phases. During the first phase, the exploratory phase, fields were selected for survey either because they seemed likely places where artifacts might be found or because they were in areas that we had not visited before. During the second phase, the probabilistic sample phase, a systematic unaligned transect design was used to select the fields for survey. During the third phase, the problem-oriented phase, the fields selected for survey were to add to previously collected data to meet the requirements for specific research goals.

1 *INTRODUCTION*

1.1 Aims and conditions of the survey

After securing professional and financial support to conduct a surface survey of the Agro Pontino, the authors set three general goals: (1) to describe the distribution of archaeological surface materials in the Agro Pontino as accurately as possible; (2) to place these materials in a rough chronological framework; and (3) to determine for each prehistoric period the factors—prehistoric cultural factors, recent cultural factors, and/or geological factors—contributing to the distribution observed. Accomplishment of these goals would provide a firm basis for substantive research questions to be addressed.

Certain geological and cultural conditions affected how we bounded the survey area. Today, the only conditions that set the Agro Pontino plain off from its surroundings are physiographic ones—the Tyrrhenian Sea on its southwestern and southeastern sides, the Lepini Range along its northeastern side, and, more diffusely, the rolling tuff-covered hills on its northwestern side at about the level of the Fiume Astura. Culturally and socio-economically, with its agriculture, horticulture, light industry, and tourism, the Agro Pontino is fully integrated into Central Italy. But this has not always been the case historically (see Koot, this volume). Because the prehistoric situation is unknown and survey conditions in the inland montane and intermontane areas are very different, it was decided to confine survey to the physiographic boundaries of the plain rather than attempt to draw more extensive, but arbitrary ones.

With regard to boundaries, it should be noted that a major physiographic boundary, the Tyrrhenian Sea, has fluctuated through time. Today, the area of the Agro Pontino is about 757 km^2; its maximum length and width is about 60 km and 15 km, respectively. Assuming a 100 m lowering of present-day sea level, the area could have been as much as 1390 km^2 during the height of the last glaciation, around 20,000 years ago. This means, of course, that there is little hope of defining the variability of the archaeological record representing periods of low sea level throughout the region.

Modern developmental conditions constricted the survey area even further. When the survey began in 1979, approximately 25 km^2 of the area was urban development—the towns of Latina, Terracina, Sabaudia, and Pontinia, and the summer houses along the Southeast coast; another 120 km^2 consisted of dispersed development, such as farmhouses, glasshouses, roads, and rural villages (Borgo Ermada, Borgo Podgora, etc.). Since that time urbanization, particularly around Latina and Terracina, has continued unabated, but most striking is the increase in dispersed development—enclaves of apartment complexes, lots with buildings for light industry, and consumer-oriented roadside businesses. These developed areas, which altogether constitute about 20% of the area, cannot be surveyed. The Parco Nazionale del Circeo, a natural reserve of about 57 km^2 established in 1934 in the southern part of the area, was excluded because conditions there were not propitious for survey—difficulty in mapping, lack of tillage, much ground vegetation, etc. In 1975, the Parco was considerably extended north and south of Sabaudia along the coast to preserve the coastal marshes.

Much of the rest of the Agro Pontino remains under the plough, although some areas are used as pasture. The rural plots, laced with drainage and irrigation canals, are sufficiently stable to identify individual fields on aerial photographs, taken in the 1950s, while on the ground. They were the obvious choice for the observation unit, or sampling unit (and later the sampling element), also because visibility conditions in each field are uniform, but vary greatly among fields.

The total surveyable area was calculated to be about 535 km^2. Altogether the fields provide a kind of grid for the survey region, although the fields themselves are not uniform in size and shape.

1.2 Three-phase strategy

The sampling strategy for surveying the Agro Pontino evolved through three phases, with the results of one phase being used for making decisions about the next phase. When drawing up the design for a probability sample, we began to conceive of the overall sampling strategy as a step-wise one consisting of:

a. An exploratory phase during which we tried to survey a few fields from each of the soil units defined by the soil survey, initially only soil units along the coast, and to survey continuously in several areas to determine artifact dispersion. Also included in this phase were fields in which the soil survey had found artifacts and fields that we thought were more suitable for hunter-gatherer habitation, e.g., on elevated places along drainage channels. The information collected from these fields was used to develop methods for assessing factors affecting visibility (see Verhoeven, this volume) and to estimate the size of a randomly selected sample required to make statements about the population of fields in the entire Agro Pontino.

b. A probability sampling phase, for which a systematic non-aligned transect design was selected to ensure (1) a sufficient sample size for making probability statements about the archaeological populations in the Agro Pontino as a whole, (2) a sample that spatially "covers" the NE-SW length of the Agro Pontino plain and is thus theoretically capable of detecting NE-SW variability in the populations, and (3) a sufficient sample size from three environmental strata (the coastal formations, the aeolian area, and the graben) to make probability statements about the archaeological record in relation to soil parent materials.

c. A problem-oriented phase, during which additional materials were collected to help accomplish specific research goals. Using the results of the transect survey and analyzing them in the context of H. Kamermans's land evaluation research—which is the basis for the investigation of man-land relationships through time in the area—additional, but shorter transects were drawn across certain areas with land units (as defined by Kamermans) that were proportionately underrepresented in the probability sample. A second sample was collected to increase the size of collections of palaeolithic materials for S. Loving's research on the Middle-Upper Palaeolithic transition.

The remainder of this article gives details about these three phases.

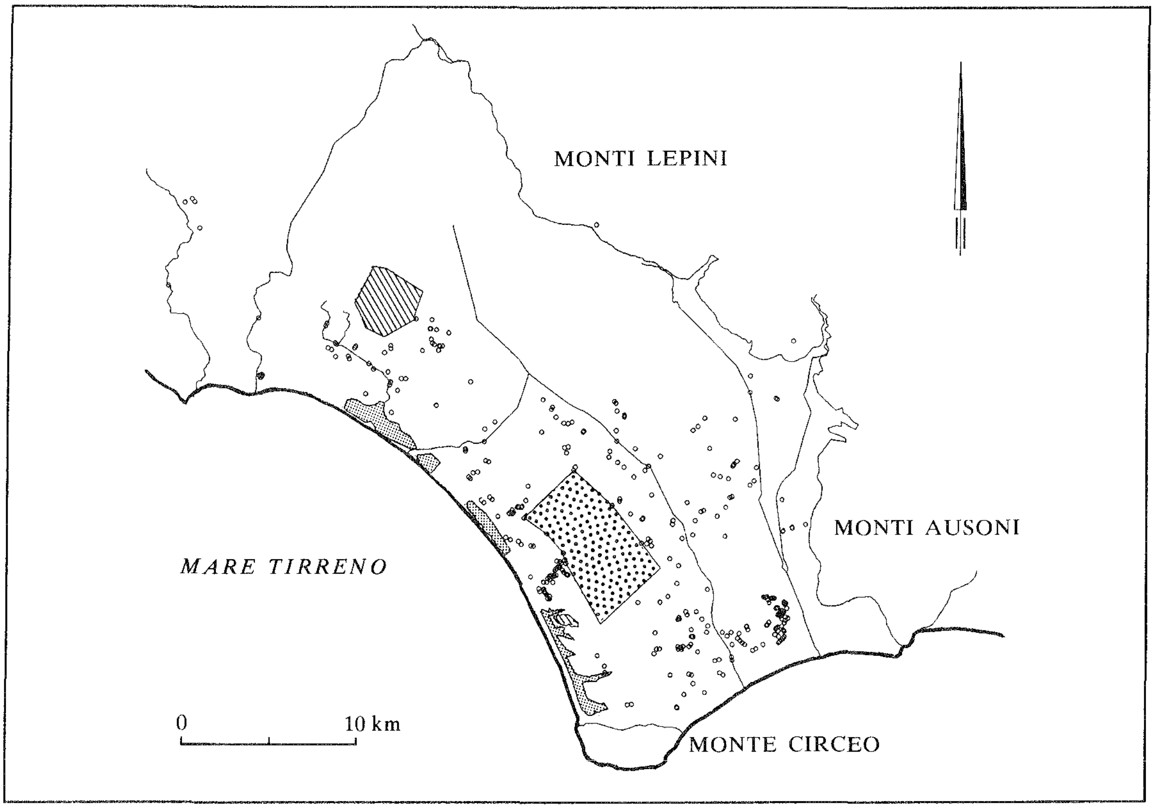

Figure 1. Location of fields surveyed during the exploratory phase.

2. *THE EXPLORATORY PHASE*

Two kinds of survey were done during the exploratory phase, (1) spot-checking different soil units and physiographic features and (2) continuous survey in several areas. Most of this coverage was restricted to the southern and central parts of the Agro Pontino, and there was no survey in the northernmost part of the survey area because the soils had not yet been mapped. The exact field selected for survey was largely dependent on what we believed were good conditions for survey, i.e., little or no vegetation and a rained-out, or recently watered, surface.

Initially, we were expecting to do a "complete" survey of the Agro Pontino, that is, to survey all surveyable fields. But, as our field methods developed (see Loving and Kamermans, this volume), it became apparent that a complete survey would be far too time-consuming.

2.1 Spot-checking different soil units and physiographic features

The sample of agricultural fields surveyed included those shown to us by the soil scientists, those reported in the literature, and those we selected because they were in a particular soil unit or because we thought they were in a good physiographic location (near a water supply, on an elevated part of the landscape, etc.). Two isolated profiles and 254 fields were surveyed (see Figure 1), including the two reported in Bietti's 1969 article and one shown to us by Sevink on the Colle Pareto, from which a collection was on exhibit in San Felice Circeo.

2.2 Continuous survey

A disadvantage to the spot-checking strategy was that most of the sample consisted of isolated fields, or at most two contiguous ones. Thus, we had very little idea about the variability in artifact densities in the various soil units and on different types of physiographic units across the landscape. Accordingly, we surveyed two areas—the Borgo Ermada level between San Felice Circeo and Terracina (46 fields) and the younger aeolian-older gravelly ridge interface north of Sabaudia (42 fields)—as continuously as possible (see Figure 1).

2.3 Results

The total area surveyed by the end of the exploratory phase was approximately 5.09 km^2. This figure, however, included .64 km^2 surveyed more than once, and thus only about 4.45 km^2 was surveyed at least once.

During the exploratory phase, 342 fields and 2 isolated profile sections were surveyed, and 260, or 75.6%, of these contained archaeological materials. Frequencies of artifacts ranged from 1 to 533 per field or profile section. The distribution of their frequencies among the fields with finds was highly skewed to the right (mean = 21.5, st. dev = 47.31, skewness = 7.16), with about 75% of the fields containing a fewer number of artifacts than the mean.

Since the agricultural field was both sampling unit and sampling element, it seemed reasonable to use the data to look at the variation in field size. The agricultural fields are, of course, more "real" than an archaeological grid, but we made the assumption that the fields, like a grid, have no correlation with prehistoric activities and could serve an equivalent function for registering the position of prehistoric artifacts. A problem is that the spatial distribution of artifacts affects the probability that non-contiguous grid units of various sizes and shapes will pick up the presence or absence of artifacts or particular artifact types. Since only complete survey, which was not feasible, would eliminate this problem, we decided to concern ourselves with conditions that would systematically bias the sample. An obvious source of bias is the different types of sediments and soils, which could affect both the size of modern agricultural fields and the distribution of activities in prehistory.

To check whether there were any systematic differences in field size according to sediments, 342 field sizes in the five vegetational zones (see Figure 2; Table 1) that had been defined for the interpretation of the Mezzaluna pollen core (Eisner *et al.* 1986) were analyzed using an analysis of variance (ANOVA). The distribution of field sizes was highly skewed to the right; after transformation of field size into its logarithm, it was

TABLE 1. DATA ON FIELDS SURVEYED DURING THE EXPLORATORY PHASE, SHOWN BY VEGETATIONAL ZONE.

Vegetational zone	Total number of fields	Mean size of fields, m^2	Systematically surveyed fields with finds: Number	Systematically surveyed fields with finds: Artifact density per hectare
aeolian	123	13,786	89	78.0
Latina lagoon	57	12,812	30	27.8
peaty graben	39	11,026	26	57.2
colluvium	7	13,521	-	
beach ridge-lagoon	116	13,128	73	72.6

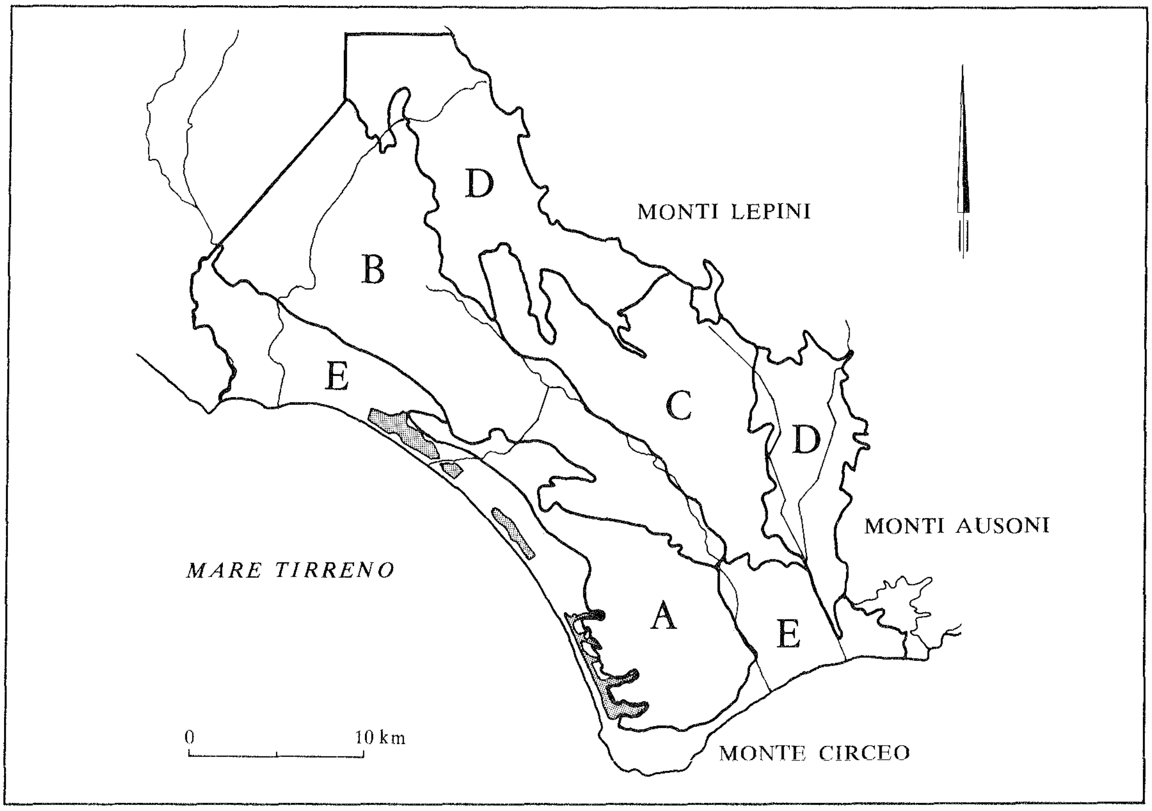

Figure 2. Map of the Agro Pontino showing the five vegetational zones. A: aeolian sands; B: (Latina) lagoonal clays; C: peats and humic clays; D: colluvium; E: beach ridge-lagoon mosaic of sands and clays.

found that field sizes among the zones were not sufficiently different to reject the null hypothesis that field sizes in all zones were drawn from the same population (df = 4, F = .22, p = .925). In other words, there was no reason to think that field size was dependent on these zones.

Artifact densities were also calculated using the first collections of the 218 systematically surveyed fields with finds (Table 1). 'Systematically surveyed fields' are those fields surveyed such that it was possible to calculate the actual surface covered. Kolmogorov-Smirnov two-sample tests showed that this subset did not differ significantly from the whole sample in either the distribution of frequencies of artifacts nor that of field sizes.

The calculated density of finds per hectare in the systematically surveyed fields ranged from 1.68 to 840 per hectare, with a mean of 70 finds per hectare (st. dev.= 100; skewness = 3.847). These statistics indicated a very large number of fields with low densities and a few fields with high densities.

Artifact densities were higher in the aeolian and beach ridge-lagoonal areas than in the peaty graben and lowest in the Latina level areas. No fields in the colluvium were systematically surveyed during the exploratory phase. The differences among the vegetational zones in artifact densities were significant at the .05 level (df = 3; F = 6.60). The artifact densities on the Latina level, however, were so far departed from the mean compared with those from other zones that they seemed to be responsible for the results. To check this, the Latina level densities were selected out and the analysis rerun. The results (df = 2; F = 1.00; p = .370) indeed showed that the major difference among the zones was the low artifact densities on the Latina level. But, because, except for the Latina level, differences were not very pronounced, it was decided not to stratify the area by vegetational zone in the probabilistic sample.

The comparison of the logarithms of artifact densities between fields in the spot-checking sample and those in the continuous samples showed that although the spot-checking sample had a far greater range of densities, the null hypothesis that the two samples were drawn from the same population could not be rejected (t = .13; df = 235). From this result it was inferred that a spot-checking sample would be as adequate as a continuous one as long as analyses were confined to associations between artifacts and environmental factors and to variability among artifact collections. A spot-checking sample, however, would not allow questions about "site" size and internal variation within "sites" to be addressed.

3 *PROBABILISTIC SAMPLING PHASE*

3.1 Design selection

For the second phase, a systematic unaligned transect sample was used to select the elements for the probabilistic sample. The ambivalence that the exploratory phase sample produced as far as defending a stratified design, with vegetational zones as the strata, made this seem the more expedient choice. It allowed the sample to retain the approximate proportions of the environmental zones present in the Agro Pontino as a whole, and, at the same time, provided a way to cross-cut the major axis of environmental variation on the plain. It was decided to make spatial strata, hereafter referred to as blocks to avoid confusion, of equal size across the length (NW-SE) of the Agro Pontino and to randomly select at least one transect within each block. The transects were to be drawn NE-SW from the mountains to the Southwest coast, thus crossing the colluvium, the graben fill, the Latina level lagoonal deposits, aeolian sands, and finally the series of coastal beach ridge-lagoon deposits (see Figure 3). The position of the blocks would reflect the NW-SE differences in the extension of the aeolian sands and the beach ridge-lagoon complex. In this design the sample element was the same as the observation unit, the agricultural field.

3.2 Selection of sample size

It was first necessary to estimate the total number of agricultural fields in the Agro Pontino. Using data that we had on 374 elements (we had recorded the area of a number of fields that we did not survey), the distribution of field size was calculated: range = 100-137,750 m^2; median = 9064 m^2; mode = 4297 m^2; and mean = 12,878 m^2 (st. dev. = $\pm$ 13,674 m^2). Since the distribution of field sizes was highly skewed to the right (skewness = 4.189), and only 23% of the fields were larger than the mean, the median was deemed a better statistic for estimating the number of fields in the region than the mean or the mode. The total surveyable area, 535 km^2, divided by the median value yielded approximately 59,000 fields.

In order to decide how many blocks and transects to draw, it was necessary to know how many fields would be crossed by a single transect and how large the sample should be. By counting the number of fields along several lines from the coast to the mountains, it was ascertained that an unobstructed transect (i.e., one that did not cross an urban area, the park, etc.) could be expected to yield about 150 fields. The sample size required was not so easily estimated because it varies according to the parameter queried and to the size of the error of estimation one is willing to accept Thus, four general questions about the archaeological record were asked, and, using the first phase sample results as estimators of variance, the sample sizes required for a simple random sample to provide answers at the 95% confidence level were calculated. The formula used in questions 1, 3, and 4 below is:

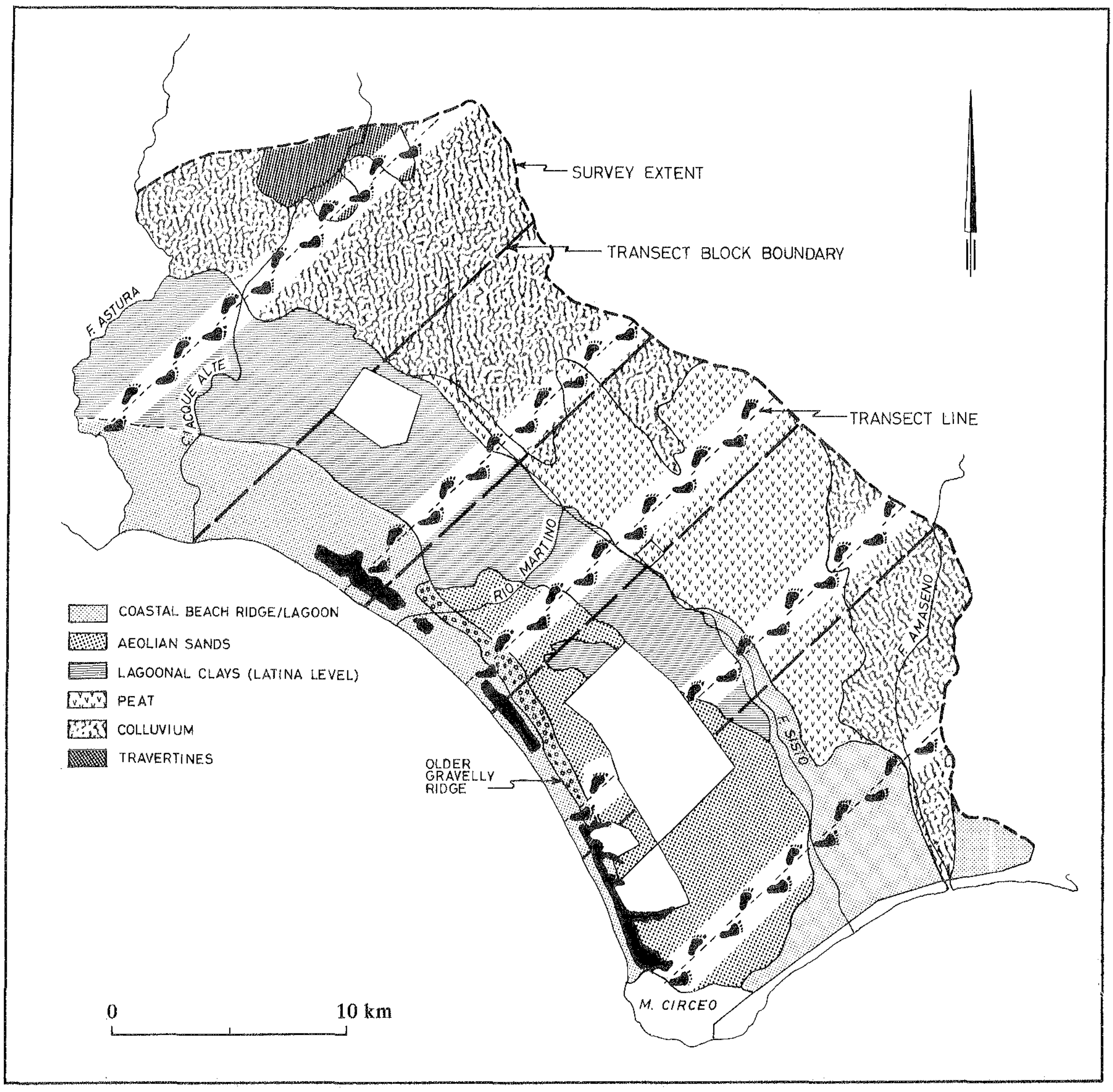

Figure 3. Map showing the division of the area into five blocks and the location of the five transects drawn for the probabilistic sample phase.

$$n = \frac{Npq}{(N - 1)\, D + pq},$$

where: n = sample size required;
N = number of elements in the sampling frame;
p = proportion of interest;
$q = 1 - p$;
$D = B^2/4$, where B is the bound on the error of estimation.

It should be noted that B is in the same unit terms as the estimators p and q. That is, $B = .05$ means an absolute error of ± 0.05 (Mendenhall *et al.* 1971:46).

Question 1: What proportion of fields in the Agro Pontino can be expected to contain archaeological remains?

The first phase sample of 344 surveyed fields and profiles showed that 75.6% of them contained artifacts (p = .756) and 24.4% did not (q = .244). A randomly selected sample of 293 observations would be sufficient for an inferential statement about the proportion of fields containing artifacts with an error of .05 (± 5%).

Question 2: Of the fields containing archaeological remains, what is the mean density of the remains?
Since this question concerns absolute counts rather than proportions, the formula used is slightly different:

$$n = \frac{N\sigma^2}{(N - 1)\, D + \sigma^2},$$

where: σ^2 = the population variance, estimated by the sample variance;
all other symbols are the same as above (Mendenhall *et al.* 1971:40).

The variance of artifact densities of the 213 systematically surveyed fields of the first phase sample was 10,000, and the bound on the error of estimation was set to ± 10/ha, yielding n = 398. This result, however, was 398 fields with finds, and the estimate from the first phase sample was that only about 75% of the fields would contain artifacts. The estimate for the number of fields that would have to be surveyed to secure 398 fields that contain one or more artifacts, with a .95 probability, was calculated as the biggest root of the equation for the binomial distribution with p = 0.75,

$$0.75 \times n - 1.96 \sqrt{0.75 \times 0.25 \times n}$$

The solution was 557.

Question 3: What proportion of fields contain materials of various time periods?
In the first phase sample, archaeological materials in 281 fields had been dated in a preliminary way. A number of these fields had materials from more than one time period. We decided to set B at one-tenth of the proportions of interest as estimated from the first phase sample, with a maximum of 0.05. Thus, the error of estimate would never be more than 10% of the proportion of interest (p) found in the first phase sample (Table 2). Following a more precise dating of materials and finer chronological divisions, it was thought probable that certain time periods would be represented in even lower proportions. If so, we would most likely have to accept a wider bound on the error of estimation since making additional observations would not be possible.

Question 4: What proportion of fields contain materials of a density of 20 finds or more per hectare?
The frequency distribution of find densities showed that there were a very large number of fields with a low density of finds and a very small number of fields with a high density of finds. A greater density of finds is desirable for a number of reasons, such as a higher

TABLE 2. SAMPLE SIZE REQUIRED TO ESTIMATE THE PROPORTION OF FIELDS, WITH A .05 ERROR, IN THE AGRO PONTINO CONTAINING MATERIALS REPRESENTING THREE PREHISTORIC PERIODS.

Period	Present (p)	Absent (q)	B	Number of observations required
Middle Palaeolithic	.375 (129)*	.625 (215)	.0375	664
Upper Palaeolithic/Mesolithic	.401 (138)	.599 (206)	.0401	593
Neolithic/Bronze Age	.392 (135)	.608 (209)	.0392	616

* Absolute counts in parentheses.

certainty for dating, detecting patterns in the relationship between finds and environmental variables, etc. The "standard" of 20/ha was the mode of the frequency distribution (which had a mean of 71.5, a st. dev. of 111.3, and a median of 36.7). Using the density sample of 213 fields (see question 2 above) from the first phase collection, 60.6% of the fields had artifact densities equal to or greater than 20/ha. The sample size required with a bound on the error of estimation of .05 was 380 observations. Again, assuming a 75% chance of locating fields with finds, a .95 probability of securing a sufficient number of fields to determine the proportion of fields with greater find density could be obtained with approximately 670 observations.

In summary, the sample size needed to obtain an acceptable estimate on the parameters queried ranged from 293 to 670 observations. Five transects were deemed the smallest sample feasible; theoretically, they would yield 750 fields, more than was needed, but we anticipated that visibility conditions, permissions, etc. would preclude survey of all the fields along each transect. The area was partitioned NW-SE into 5 blocks, each approximately 12 km wide, and a transect was randomly selected from each of the blocks. In more detail, this was done by pasting together photocopies of aerial photographs (with an approximate scale of 1:33,500) of the Agro Pontino and demarcating the five blocks. The distance between the boundaries of the blocks was 330 mm and one transect was located within each block at a distance from its northern boundary, determined by locating a place in a random numbers table (using the date we were doing the selection to find the starting digit), and then taking three successive digits until five combinations of less than 330 were found. A digit combination of 240, for example, would mean that a point 240 mm from the northern border of one of the five blocks would locate where the transect line was to be drawn from mountains to the southwest coast parallel to the dividing lines between the blocks.

3.3 Results

Altogether, 727 fields and one isolated profile were surveyed along the five transects during the probabilistic sampling phase. The area covered was approximately 14.5 km^2. The number of fields per transect from N to S and the number per vegetational zone is shown in Table 3.

With the exception of transect 5, the differing number of fields per transect reflects the number of agricultural fields, i.e. the distances crossed, fairly accurately from N to S (transect 4 crossed the Parco). Transect 5 crossed the southernmost aeolian area where it was difficult to locate suitable fields, which, once located, were difficult to obtain permission from the owner for survey.

The average artifact density by vegetational zone is shown in Table 4. Except for zones A and D, which are reversed, the order of the sizes of areas covered in each zone agrees with the order of number of fields surveyed per zone. The dependency of field size on vegetational zone was once again evaluated with an analysis of variance after field area was transformed to logarithms, which showed that although, as before, sizes of fields in the peaty graben were smallest and those in the aeolian largest, the relationship between field size and zone was significant (df = 4, F = 6.05, p <.001). This result does not seem to be caused by a single vegetational zone and means that it is advisable to use field areas rather than field counts for most analyses.

Artifact density also seems to be dependent on vegetational zone (Table 4). A significant value of F (6.62; df = 4; p =.015) was obtained with ANOVA after densities had been transformed to logarithms. In this case, however, the result would seem to be caused by both the high densities in the colluvium (zone 4) and the low densities in the beach ridge-lagoonal area (zone 5). The latter is not evident from the mean densities, but shows up in the deviations from the mean in the transformed data (Table 4). The high densities in the colluvium may be related to the Roman materials found there, a number of

TABLE 3. FIELDS SURVEYED DURING THE PROBABILITY SAMPLING PHASE, SHOWN BY TRANSECT AND VEGETATIONAL ZONE.

	Fields per vegetational zone					
Transect	aeolian	Latina lagoon	peaty graben	colluvium	beach ridge-lagoon	Total
1	1	113	1	40	34	189
2	0	58	65	14	21	158
3	33	24	59	23	16	155
4	9	40	31	9	13	102
5	50	14	10	18	31	123
Total	93	249	166	104	115	727

TABLE 4. ARTIFACT DENSITIES IN FIELDS SURVEYED DURING THE PROBABILISTIC PHASE, SHOWN BY VEGETATIONAL ZONE.

Vegetational zone	Total area surveyed,m²	*N*	Artifact densities per hectare mean	median	Deviation from mean (log)
aeolian (A)	2,212,197	62	41.1	18.2	-.04
Latina level (B)	4,944,776	176	86.4	19.7	-.02
peaty graben (C)	3,089,312	98	68.6	17.9	-.04
colluvium (D)	1,940,780	77	139.2	32.8	.47
beach ridge-lagoon (E)	2,339,157	70	39.5	11.9	-.36

TABLE 5. THE ESTIMATED PROPORTION OF FIELDS SURVEYED DURING THE PROBABILITY SAMPLE PHASE WITH ARTIFACTS OF DIFFERENT TIME PERIODS.

Time period	Number of fields	*p*	*q*	*B*	Range at .95 level
Middle Palaeolithic	197	.271	.729	.0329	23.8-30.4%
Upper Palaeolithic	106	.145	.855	.0259	11.9-17.1%
Epipalaeolithic	114	.156	.844	.0267	12.9-18.3%
Mesolithic	15	.021	.979	.0105	1.1- 3.2%
Neolithic	90	.123	.877	.0242	9.9-14.7%
Bronze Age	12	.016	.984	.0092	0.7- 2.5%
Iron Age	72	.099	.901	.0220	7.7-12.1%
Archaic	147	.202	.798	.0296	17.2-23.2%
Roman	280	.384	.616	.0359	34.8-42.0%
Post-Roman	93	.127	.873	.0245	10.3-15.2%

which are probably the remains of real "sites". It is interesting that the beach ridge-lagoonal zone, where so much of the exploratory phase efforts were concentrated, has the lowest artifact densities in the transect sample.

The results from the transect survey made it possible to make some statements about the archaeological record of the Agro Pontino. First, the population parameters queried in the previous section were estimated.

The first question concerned the proportion of fields that could be expected to contain artifacts. Of the 729 fields on the transects, 500, or 68.6%, contained archaeological finds. This was 7% less than the initial estimate. By solving for *B* in the equation for estimating population proportions in the previous section (*B* =. 0342), it was found that there is a .95 probability that the proportion of agricultural fields with artifacts in the Agro Pontino ranges from 65.2% to 72.0%.

The second question concerned the mean density of artifacts in fields with finds. Of the 500 fields with artifacts, artifact densities could be calculated for the 489 that had been systematically surveyed at least once. Densities ranged from .093/ha to 4513.887/ha, with a mean of 80.358, a standard deviation of 310.869, a median of 18, and a mode of 8. These data showed far more variation than those calculated from the exploratory phase sample. First, the range of densities in both directions was considerably extended; second, the mean and the standard deviation were greater; and third, the median and the mode were located at much lower densities. The transect survey seems to have picked up many more fields with low densities, but, more importantly, some fields with an extremely high density of artifacts. How accurate was this picture? Again, solving for *B* (*B* = 28.024), there was a .95 probability that the mean of the artifact densities in individual fields ranges from 52.334/ha to 108.382/ha. This, of course, was a much wider error of estimation than we had hoped for.

In trying to account for this variation, lithic and ceramic densities were calculated separately. The lithic densities (n = 310) ranged from .093/ha to 557.018/ha, with the skewed frequency distribution having few gaps up to a density of about 220/ha and having one outlier at 557.018/ha (mean = 24.972; st. dev. = 45.407; mode = 22.22; median = 10.39). The error of estimation for the density of lithic artifacts was 5.147 even without removing the outlier, indicating that there is a .95 probability that the mean density of lithic artifacts ranges from 19.82/ha to 30.12/ha. The ceramic densities (n = 306) ranged from .379/ha to 3011.288/ha and had even a higher variance than the total artifact sample (mean = 93.406; st. dev. = 313.543; mode = 25.0; median = 16.173). Removal of the fields with 'scatters' (sub-samples within fields with a high number of artifacts) did not improve the result; the extremely high densities came from estimates of the number of artifacts seen but not collected in the field. Interestingly, the frequency distribution showed one series of values to about 900/ha and a second from about 1500/ha to 3000/ha. It is certainly clear that within the sample of ceramic densities there are subgroups that will require different sets of archaeological interpretations. Further analysis will be required to decide how many subgroups there are and which sets of interpretations will be most appropriate for each.

The third question concerned the proportion of fields with artifacts from various time periods. Estimates for these proportions are shown in Table 5.

None of the estimates, except for the Roman period, were within the selected bound on the error of estimation (.05), the problem being that the proportions of interest are less than originally thought and, consequently, the sample size is too small. The estimates are valid, however, and certainly serve as a good first approximation; it is just necessary to accept a wider bound on the error of estimation than was hoped for.

The fourth question concerned the proportion of fields with densities of 20 artifacts/ha or more. Among the 489 systematically surveyed fields, 227, or 46.4%, of them had at least this high an artifact density. The bound on the error of estimation was .0036, giving a .95 probability that the proportion lies between 46.0% and 46.7% of the fields with finds.

4 PROBLEM-ORIENTED PHASE

The third phase was the purposive selection of observations needed for specific research goals. For example, it may be desirable to predict where certain types of sites should be and then check the predictions in the field, or for some studies it may be necessary to enlarge existing collections of archaeological material. The major purpose of the third phase was to fill in informational gaps so that the studies using primarily survey data could be completed.

4.1 Land unit sampling

The first problem-oriented research project developed concerned man-land relationships. The purpose of the research is to adapt the land evaluation technique to regional archaeology.

4.1.1 Introduction to land evaluation and its application to archaeology

Land evaluation is a technique developed by the FAO and used in Third-World countries for estimating the potential of land for alternative kinds of use. The definition is as follows: "the process of collating and interpreting basic inventories of soil, vegetation, climate and other aspects of land in order to identify and make a first comparison of promising land use alternatives in simple socio-economic terms" (Brinkman and Smith 1973:7, fig 1). The basic feature of land evaluation is the comparison of the requirements of land use with the resources offered by the land. Land evaluation requires information from three sources: land, land use, and economics.

There are some important differences for using land evaluation in archaeology (Kamermans *et al.* 1985). First, it is, of course, impossible to measure prehistoric land qualities directly; they have to be reconstructed from data obtained by surveys of the recent land characteristics. Second, the economic and social analysis of the approach as used in physical geography has to be replaced by models of prehistoric socio-economic situations. To construct these models, information on the ecological and technical requirements of different kinds of land use as well as data on the economic and social context has to be generated by using ethnographic, archaeological, and historical sources. The outcome is an expected form of land use for each socio-economic model. Third, the purpose of using the land evaluation approach in archaeology is to evaluate our models. The comparison of the expected form of land use with the archaeologically recorded land use provides a basis for modifying the models. We repeat this procedure until the outcome fits best with the archaeological record.

4.1.2 The sample needed for the research

For the land evaluation research the Agro Pontino was divided into 17 land units on the basis of physiographic and geological parameters. For each marine terrace all the different beach ridge deposits were grouped together, but the lagoonal deposits were split into coastal and inland units. The result was 12 land units for the four marine terraces. The aeolian, the tuff, the travertine, the alluvial/colluvial deposits and the recent valley fills form the other five land units (Table 6).

To use the survey data for this research, it was necessary to have a sample of all the different land units and desirable that the surveyed area of each unit was proportional to its area in the region. First the area of each land unit was established (Table 6) and the proportion of the different units was calculated. Then the surveyed area for every land unit was calculated, and finally its percentage.

4.1.3 Evaluation of the probabilistic sample and selection of additional transects

In the data collected during the probabilistic sampling phase one of the units was not represented at all (the travertine), and some of the units were underrepresented (the Terracina level, the Borgo Ermada coastal lagoon, the Minturno inland lagoon and the alluvial-colluvial deposits). The Borgo Ermada coastal lagoon and the Minturno inland lagoon were only slightly underrepresented, however, and it was thought problematic that more data could be collected on the Terracina level because of the housing developments located there. Consequently, it was decided to concentrate on collecting more data from the travertine and alluvial/colluvial units. Using the same procedure for selecting transects in the probability phase, three new shorter transects were randomly selected, one crossing the travertine and two crossing the alluvial-colluvial unit.

4.1.4 The land unit sample after further collection

The final result (Table 7) shows that most land units are now well represented. The physical and archaeological properties of the different land units will be used to predict and evaluate certain kinds of land use for different time periods ranging from the Middle Palaeolithic to the Bronze age.

4.2 Palaeolithic site sampling

A second research project using survey data concerns differences in human mobility between the Middle and Upper Palaeolithic periods. The research uses all the Palaeolithic periods represented on the Agro Pontino, i.e., from the Middle Palaeolithic through the Epipalaeolithic, and the research design calls for recollection of surfaces in places where previous collections are inadequate.

Table 6. Total area and area surveyed of each land unit during the probability sample phase.

	total area		surveyed area	
	km^2	%	m^2	%
Terracina beach ridge	21.21	2.84	27,300	0.29
Terracina coastal lagoon	21.73	2.91	99,050	1.06
Terracina inland lagoon	117.67	15.77	1,420,680	15.24
Borgo Ermada beach ridge	9.36	1.25	176,469	1.89
Borgo Ermada coastal lagoon	41.03	5.50	646,660	6.93
Borgo Ermada inland lagoon	65.97	8.84	820,315	8.80
Older gravelly	5.22	0.70	115,972	1.24
Minturno beach ridge	4.14	0.55	62,850	0.67
Minturno coastal lagoon	10.44	1.40	116,200	1.25
Minturno inland lagoon	5.72	0.77	110,525	1.19
Latina beach ridge	3.93	0.53	119,230	1.28
Latina lagoonal	124.06	16.63	1,662,226	17.83
Aeolian	99.63	13.36	1,823,943	19.56
Tuff	14.93	2.00	535,700	5.74
Travertine	12.52	1.68	0	0.00
Alluvial/colluvial	178.36	23.91	1,496,027	16.04
Recent valley fills	13.58	1.82	91,525	0.98
Agro Pontino	745.98	100.00	9,324,672	100.00

TABLE 7. TOTAL AREA AND AREA SURVEYED OF EACH LAND UNIT DURING THE PROBABILITY SAMPLE AND THE PROBLEM-ORIENTED PHASES.

	total area		surveyed area	
	km²	%	m²	%
Terracina beach ridge	21.21	2.84	27,300	0.25
Terracina coastal lagoon	21.73	2.91	99,050	0.91
Terracina inland lagoon	117.67	15.77	1,420,680	12.99
Borgo Ermada beach ridge	9.36	1.25	176,469	1.61
Borgo Ermada coastal lagoon	41.03	5.50	646,660	5.91
Borgo Ermada inland lagoon	65.97	8.84	865,865	7.92
Older gravelly	5.22	0.70	115,972	1.06
Minturno beach ridge	4.14	0.55	62,850	0.57
Minturno coastal lagoon	10.44	1.40	116,200	1.06
Minturno inland lagoon	5.72	0.77	110,525	1.01
Latina beach ridge	3.93	0.53	119,230	1.09
Latina lagoonal	124.06	16.63	1,662,226	15.20
Aeolian	99.63	13.36	1,823,943	16.67
Tuff	14.93	2.00	535,700	4.90
Travertine	12.52	1.68	370,875	3.39
Alluvial/colluvial	178.36	23.91	2,694,112	24.63
Recent valley fills	13.58	1.82	91,525	0.84
Agro Pontino	745.98	100.00	10,939,182	100.00

4.2.1 The type of sample needed for the project

The unit of analysis to be used for one part of the research is the individual artifact; previous collections are considered satisfactory for this aspect. Another part of the research, however, entails considering different collections as if they were assemblages, i.e., using a collection as the unit of analysis. The purpose is to assess differences in mobility by comparing the structure of collections, using an index of diversity, which is known to be highly sensitive to sampling bias. Thus, the problem was to design a method to help us decide on the adequacy of a collection.

4.2.2 Selection of sites for additional collection

Pielou (1975) provides a method for assessing the size of samples needed to estimate the diversity of an ecological community. Plots of samples successively incremented in size will reach an inflection point in the curve, t, when the sample size required to "stabilize" the diversity index is reached. This was the kind of measure needed to assess collections. What size of sample was required so that the addition of more artifacts would not notably change the index of diversity?

It was necessary to develop another approach than that used in ecology, however, because certain aspects of the archaeological data violated the assumptions about the population used in the ecological measure. Both the number of individuals and the number of species in the ecological population are assumed to be infinite. The number of lithics present at a site, from which the archaeological sample was drawn, is certainly not infinite; moreover, the number of classes of lithics, analogous to species, is arbitrary and decided by the researcher.

We, therefore, created nine classes of lithic artifacts that we thought would not be chronologically sensitive since we were not interested in measuring diversity caused by chronological differences: scrapers, points, burins and borers, other retouched pieces, other utilized pieces, cores, other flakes and blades, blocks and other resharpening pieces. We then excluded all sites with less than 20 lithic artifacts and distributed the artifacts from the other sites over the nine classes. For each site in turn, a random sample of ten artifacts was taken, with replacement, and the diversity index of the sample calculated. This process was repeated 100 times. The diversity index used was

$$H_2 = 1 - \sum_{i-1}^{s} \pi_i^2 \quad \text{(Bobrowsky and Ball 1989)}$$

Then the standard deviation of the 100 indices was calculated. Next the size of the random sample was increased by one and the calculations repeated until the sample size equalled the size of the collection, at which point the standard deviation, of course, dropped to zero. The standard deviations of the diversity indices were then plotted against the sample size, using the running mean over five observations. The curves thus begin with a sample size of 12 and end with a sample size that equals the size of the collection minus three. In Figures 4 to 7 the horizontal axes have been scaled to sample sizes 12 to 100 to make the figures comparable. Figures 4 and 5 show the difference between adequate and inadequate samples. The curve for the inadequate sample is almost vertical and more or less straight, whereas the curve for the adequate site completes a bend changing from vertical to more horizontal, showing the stabilization of the diversity index.

Using this method, 28 previously collected sites were measured and considered adequate and 45 previously collected sites were slated for recollection.

4.2.3 Results

Of the 45 sites slated for recollection, it was possible to recollect 20. The evaluation of these, using the same method, showed that 13 of them could be considered adequate. Figure 6 shows the curve for site 357 after it was recollected. Thus, theoretically, there are 41 sites that can be used in the analysis of site structure.

All sites with more than 70 items had curves that went from vertical to horizontal, but some of these curves became horizontal at a lower sample size. The sample size at which the curve bends is related to the inherent diversity of the sample, its richness and evenness.

The maximum richness is predetermined by the number of classes used. To see the effect that this had on the curve, the number of classes was increased to 15 by subdividing the retouched pieces, the utilized pieces, flakes/blades, cores, blocks, and resharpening pieces into broken and unbroken categories. The artifacts of six sites, whose sample sizes ranged from 68 to 201, were reclassified and the analysis run again. The curves based on nine classes and those based on 15 were very similar in each of the six cases (compare Figures 5 and 7). Each, however, required a somewhat larger sample size before reaching a more or less stable diversity. This is not just a result of increasing richness, but also of the change in evenness that occurred if one or more of the derived classes were considerably more or considerably less proportionately represented than the class it was derived from. The curves resulting from the 15-class runs were also more gradual than their 9-class counterparts, making the bend in the curve less sharp and interpretation of the curve more difficult. It is not as clear, for example, that the site 493 curve based on the 15-class run has stabilized (Figure 7).

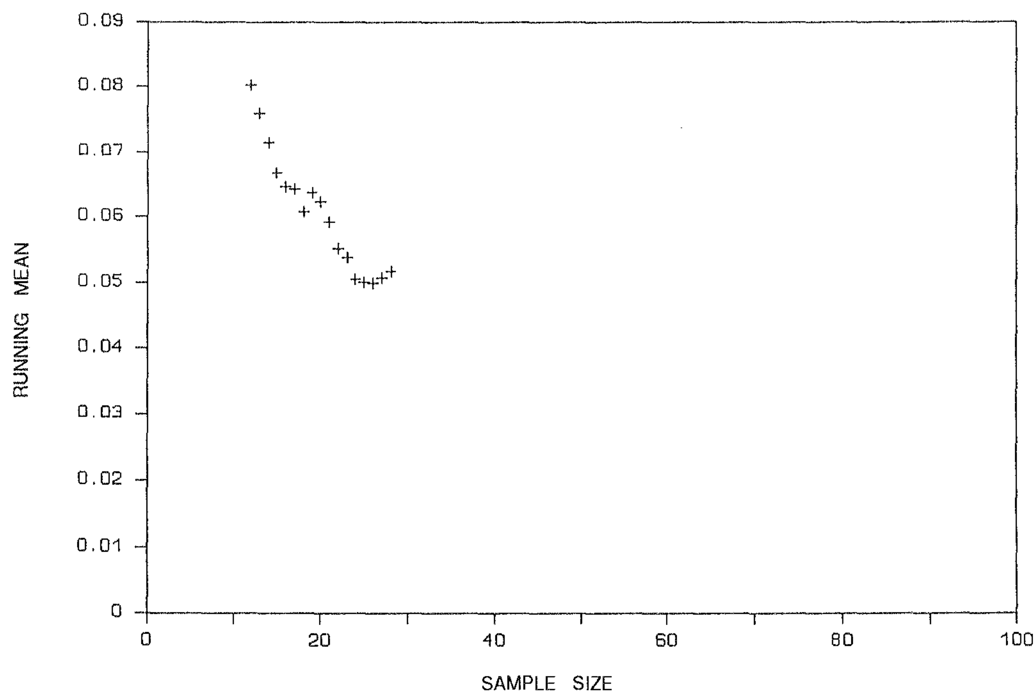

Figure 4. Site 357, illustration of an inadequate sample size. Running mean of diversity indices plotted against sample size using 9 classes of artifacts.

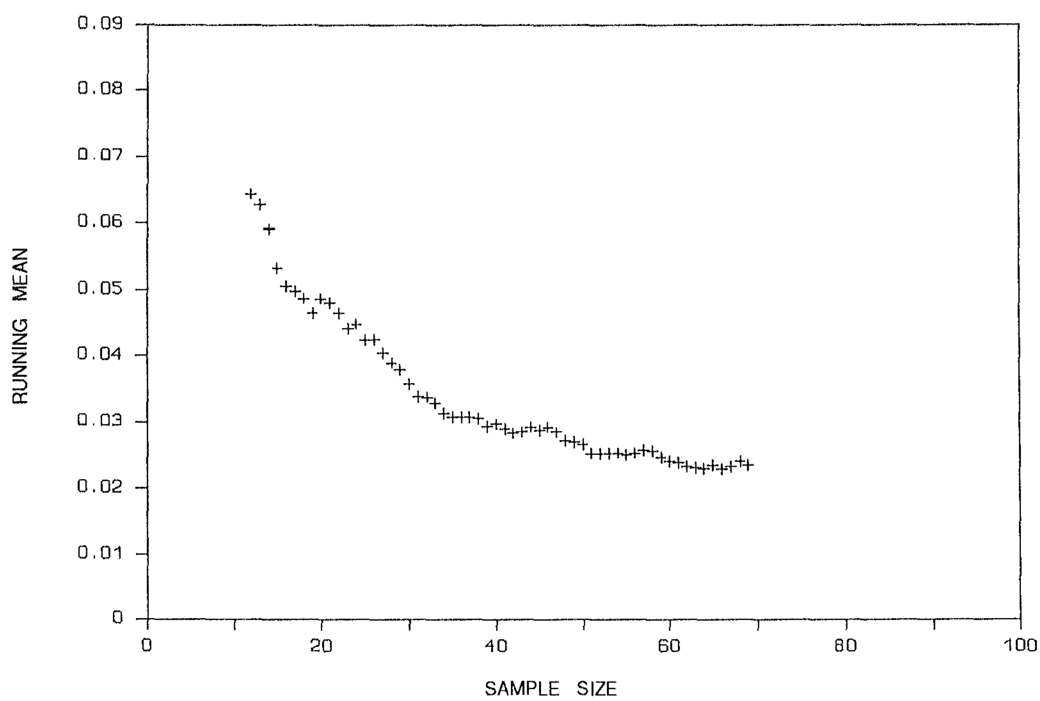

Figure 5. Site 493, illustration of an adequate sample size. Running mean of diversity indices plotted against sample size using 9 classes of artifacts.

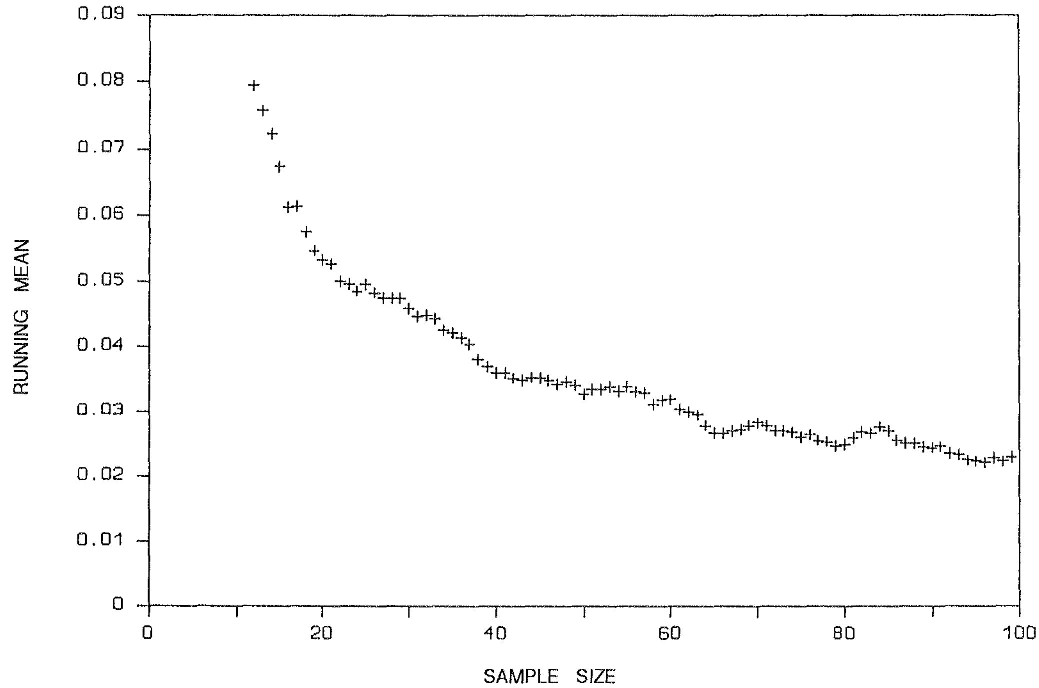

Figure 6. Site 357, after recollection, illustration of adequate sample size. Running mean of diversity indices plotted against sample size using 9 classes of artifacts.

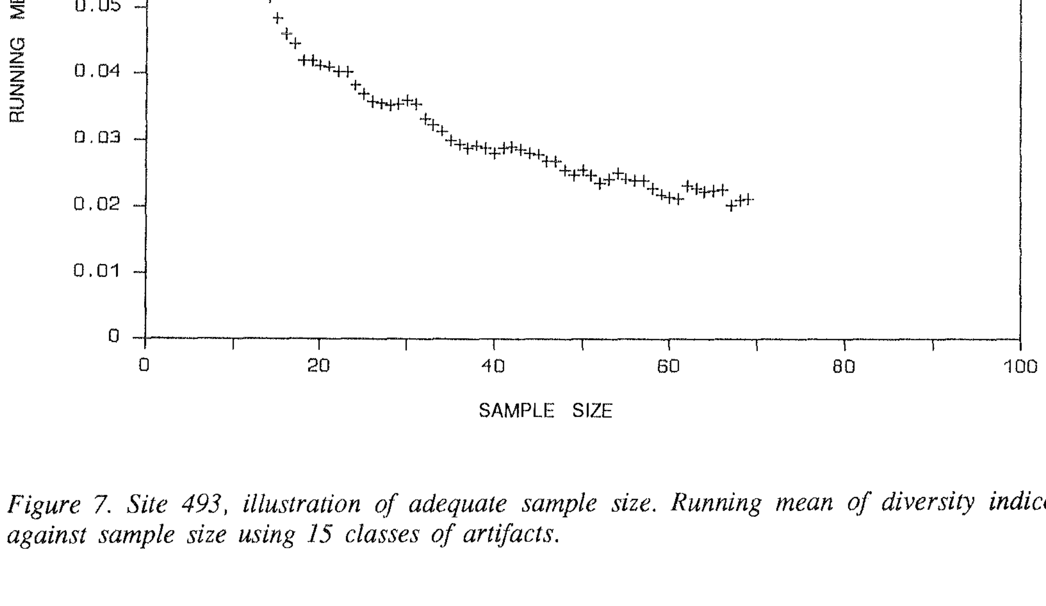

Figure 7. Site 493, illustration of adequate sample size. Running mean of diversity indices plotted against sample size using 15 classes of artifacts.

5 CONCLUDING REMARKS

The experience of the Agro Pontino survey project is a good illustration of what to expect when a probability sampling design is included in the sampling procedure. Assuming that nothing or very little is known about the region beforehand, the precision of the results of the probability sample are largely determined by the quality of the non-random sample whose statistics are used to estimate population parameters in constructing the probability design. The exploratory phase sample was misleading in two major respects. First, the variability in artifact density was lower, and second, the proportion of fields with artifacts of any one time period was higher than was actually the case. With a .05 bound on the error of estimation, the sample size calculated for determining some of the population parameters was simply too low.

Once the results of the probability sample were available, however, the range of error of our estimates was known. If that range was unacceptable, then it was very easy to calculate how many more randomly selected fields would need to be surveyed to make it acceptable. For example, if we wanted to estimate the proportion of fields with Middle Palaeolithic artifacts within a 10% error of its proportion, 27.1%, we now know we would need to survey approximately 375 additional randomly selected fields. With that sample we would be able to achieve an even closer approximation than we have. But, that, of course, is not what we want to do with the results of the probability sample.

Before the results of the probability sampling phase were available we knew very little about the distribution of surface finds, in both time and space, in the Agro Pontino. Now we know a lot: where the artifacts are found, where not, which densities tend to occur, what kinds of variations are present in assemblages, landscape associations, etc. Thus, we now are in a position to pursue our investigations in a much more purposive fashion without worrying that major aspects of the surface archaeology will be missed.

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