

Evaluating the Effectiveness of Archaeological Surveys

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The paper presents statistical methods for evaluating the effectiveness of archaeological survey strategies. Two main types of archaeological survey are discussed: continuous and discrete. These are compared to analogous military search situations and the mathematical solutions developed for the military problems are presented. Techniques for adapting these solutions to archaeological problems are discussed and examples are given of the methods of each type of search strategy.

Introduction

This paper presents two methods of evaluating the efficiency of survey strategies for discovering archaeological sites. The quality of the sample of sites gathered using a particular strategy and, by extension, the statistical validity of inferences drawn from such data, will also be touched on.

There have been several discussions on this subject before (i.e. Lovis 1976; Chartkoff 1978; Schiffer, Sullivan and Klinger 1978; Krakker, Shott and Welch 1983). The present discussion has the express purpose of bringing search theory to the attention of the archaeological community and to show how this may be applied to problems of **archaeological** research. These methods, summarized from an extensive body of literature on Search Theory, are easy to use and give accurate results, though by no means do they constitute an exhaustive treatment of possible solutions to the problems of evaluating archaeological survey strategies.

A brief discussion is in order about the nature of archaeological survey and the types of data such surveys may be intended to provide. Methods of evaluation can then be presented, and their applicability, accuracy and constraints may be discussed.

Archaeological survey, whether conducted for pure research or for cultural resource management, seeks to locate archaeological materials within a certain area. The pure researcher uses this information to test hypotheses; the contract investigator uses it to make recommendations for mitigation or preservation. Evaluating survey techniques so that

statistically defensible statements can be made about the universe of sites from which a sample was drawn should increase the probability of a correct cultural resource management decision being made.

Analyzing the techniques used to conduct archaeological surveys, and by extension the quality of the data thus gathered, is particularly relevant in these days of reduced funding and narrowing time constraints. For the contract archaeologist or the pure researcher, these pressures create a need for evaluating surveys to make them more cost-effective. Contract researchers especially will have to find the largest sample of sites possible while operating within any given set of budget, personnel and time constraints.

There exists a large body of mathematical theory for analyzing the effectiveness of searching techniques and assessing the probabilities that any given technique will detect the object sought for. It was developed during World War Two by an operations research group that had been brought together to analyze the effectiveness of techniques used against the U-boat threat. The methods are presented in their simplest form and tend to reflect a bias towards worst cases and ease of computation. There are more complex solutions to some of the examples given in this paper, but the functions presented here give results very close to those derived from more complicated methods.

The Nature of Archaeological Survey

One type of survey is described by Zubrow and Harbaugh, for whom archaeological survey is a form of prospecting (1978:109-122).

The researcher is seeking a particular site, culture, or set of artifacts, and the search is conducted until the object is found or resources run out.

In another type of survey, the desired result is a representative sample of the universe of sites within

the surveyed area. The search is continued until all of the area has been inspected in some fashion.

The Nature of the Target

The techniques of anti-submarine warfare may seem far removed from the methods of archaeology. A closer examination of the two problems, however, shows there is a great degree of similarity in both the principles and the main constraints. Let us compare two hypothetical searches: a ship hunting for submarines, and an archaeologist conducting a survey in a heavily forested environment.

The naval search is looking for submarines which, apart from variations in size and other characteristics, may be treated as a single class of artifact. There may be more than one of these artifacts to be found and their distribution may range from widely dispersed to tightly clustered.

The archaeologist's task is similar. There may be one or more objects-of-search (archaeological sites) to be found within the area to be inspected. The most directly comparable situation would occur if the archaeologist were searching for one or more monumental structures. However, most archaeological sites are actually clusters of artifacts distributed over a restricted area with definable boundaries. The areas can range in size from a few square metres to several hectares and the number of artifacts from a few to several thousands. It is the artifacts, as indicators of the presence of sites, that are actually sought in most surveys. The object or objects of the search may be on the surface and visible to the naked eye, or they may be under the surface and invisible. Each situation has different properties which the methods of searching must take into account. At the completion of the search, the naval commander or the archaeologist will want to estimate the proportion of objects that may have been missed by the search strategy employed.

In short, both naval and archaeological searchers are looking for an object or objects within an area. They may not have the resources to search the entire area. The objects may be above or below the surface of an opaque medium. Both would like a measure of how well they did and an estimator of the probability that an object was missed.

The Search

Both the archaeologist and the naval commander have two types of searching strategy they can bring into play, based on the different ways various detecting devices operate.

The first strategy is the Continuous Search in which the detection device applies its effort in a continuous fashion: the warship scanning the surface of the sea with radar and human lookouts, or the underwater environment with sonar; the archaeologist visually inspecting areas with little or no vegetation obscuring the ground.

The second strategy is the Discrete Search in which the search effort is applied discontinuously: the warship deploying sonobuoys with limited range to search small volumes of sea which may not overlap; the archaeologists shovel testing their way through a forest. In both cases the searcher is given a finite number of "looks" into small portions of the area of search and would like to know the probability of actually looking into the portion of the search area containing the object and, in fact, detecting it.

Evaluating the Continuous Search

Continuous search employs detection devices (radar, *eyes* etc.) that are moved through the search area in a continuous manner. In archaeology the most familiar form of continuous search is the surface inspection, usually employed where there is little vegetation obscuring the ground and it is assumed that archaeological materials large enough to be visible to the naked eye will be on the surface of the ground. In northeastern North America these conditions are usually found in fields where ploughing has cleared away most of the vegetation and brought archaeological materials to the surface.

Let us assume we are searching for a small hunting campsite which consists of a small scatter of lithic materials. For purposes of this illustration, let the site be a circle with radius R (a circle has maximum area with minimum perimeter). The value of R can be varied to represent any type of site from a stray find to a temple mound. The first step in evaluating the continuous search is to define the types of materials being sought. In this case the site contains a small scatter of lithic debris and this is the actual object of search. The next step is to determine the distance at which the target materials can be seen by the searchers. This detection range will be affected by things such as the size, texture, and colour of the materials as well as the conditions under which the search is conducted (clouds, oppressive heat etc.)

In *order* to detect such a site, two conditions must be fulfilled. First, the searcher must pass within his or her detection range of the site's artifacts. This condition can be met either by passing through the

site or by passing close enough to its edge to bring one or more of its artifacts within the detection range of the searcher. Second, the searcher must actually *detect* the material. If the members of the survey crew are spaced at intervals equal to the radius of the site they may pass over the site as shown in Figure 1: One searcher walks through the centre of the artifact distribution, two pass at the edges. Alternatively the lines may shift so that two searchers pass over portions of the site. It is clear that reducing the interval between crew members to R or less will raise the probability of each individual passing over the site.

Figure 2 shows a different coverage. Here a site of radius R is being sought with a spacing between crew that, at worst, will bring at least one of them within detection range of the site. Alterations in the interval between crew members would bring some of them closer to the site.

Figure 2 also shows examples of the concepts and terminology of Search Theory. The variable W is the detection range or distance at which the searcher can detect the target materials. Searchers can see the ground on both sides of their path, so actually the space on either side of the path is searched. This area is termed $2W$: the Sweep Width. The distance between the searchers is the Sweep Spacing. The area of ground that actually passes within $2W$ of the searchers is known as the Swept Area. In the situa-

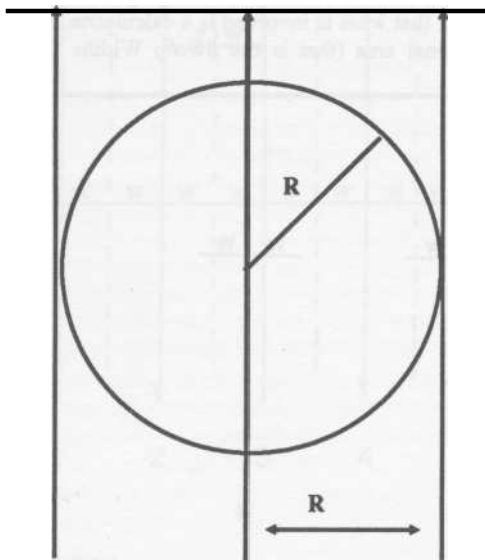


FIGURE 1
Hypothetical encounter with a site defined by a circle of Radius R and searchers spaced at R .

tion shown in Figure 2, the paths are separated by a distance equal to the diameter ($2R$) of the site and the detection range for the searchers passing on either side of the site ($2W$).

The probability of detecting the hypothetical site depends on whether or not one or more of the workers passes within detection range (W) of an artifact and, in fact, sees it. The probability of passing that close to the site depends on the fraction of the project area that was actually "swept". If one assumes the detector is perfect and the walked lines perfectly straight, with no overlapping of the swept areas, then the probability of seeing artifacts detectable at distance W is closely approximated by dividing the area swept by the detector by the project area:

Formula 1

$$P = 2WL/A$$

P is the probability of detection, $2W$ is the Sweep Width, L is the sum of distances walked by all the members of the field crew, and A is the size of the project area (Koopman 1946:28). In those cases where the archaeologist has enough time and enough crew members to allow the Sweep Widths to touch (Figure 3), and assuming the detector is perfect, the application of Formula 1 would give a probability of detection of 1.0.

Clearly, Formula 1 represents an idealized situation and a moment's consideration of the difficulties of maintaining proper spacing between field workers, keeping their paths exactly straight across the searched area, and of the idiosyncracies of each worker leads to the realization that the probability of detection is unlikely ever to reach 1.0, that is, certainty. To account for these randomizing effects that degrade certainty, search theorists use exponential functions employing Napieran logarithms of the natural base e . Where the detector is perfect, and coverage is complete (Sweep Widths touch: Fig. 3) the maximum probability of detection is shown in

Formula 2:

$$\begin{aligned}
 P &= 1 - e^{-1} \\
 &= 1 - 1/2.7 \\
 &= 1 - 0.3679 \\
 &= 0.6321 \\
 &\text{(Stone 1975:1-14)}
 \end{aligned}$$

Formula 2 represents the "best case" situation: the area searched and the track lengths are large. But even in the case of a parallel sweep search there

will be displacement and errors in the placement of the tracks (Stone 1975:14).

There are more complex detection functions which involve summing the probabilities of detection of all the tracks and using a detection function based on an inverse cube law. These functions all approach the maximum random search figure as searching continues precisely because there are errors and a law of diminishing returns is realized. The general solution is still an exponential function of the natural base *e*.

For computing the lower probabilities of detection where real values exist, these values can be entered as the exponent for *e*. To account for the actual area searched by the workers and still account for the variations in sweep widths, track bending and other randomizing events, Formula 1 can be substituted for the exponent in Formula 2. The result is Formula 3:

$$P = 1 - e^{-(2WL)/A}$$

(Koopman 1946:29)

The field workers can be evaluated as a detection unit by substituting *S* (Sweep Spacing) for *A* in the exponent. This gives us Formula 4:

$$P = 1 - e^{-(2W)/S}$$

This formula takes into account the situation shown in Figure 2 where the Sweep Widths do not touch but have been opened up so that only a

fraction of any searched area actually passes within detection range of a searcher.

The upper limit on a search of this type is obtained by Formula 5, simply the probability of the detector detecting $(2W/S)$ multiplied by the fraction of the project area actually searched, (*A*):

$$P = (2WL/S) (A)$$

This formula can yield a value of 1.0, but, as mentioned above, there are always problems preventing total coverage: search lines will never be absolutely straight and distances between workers will vary. If searchers are so spaced that the Sweep Widths overlap, a lower limit on probability of detection may be derived from Formula 6, where Sweep Width (*2W*) and Sweep Spacing (*S*) are used in the exponent of the natural base *e* to account for the uncertainties of the detector's actually detecting:

$$P = 1 - e^{-[(2W)/S](A)}$$

(Koopman 1946:30)

Let us assume that a project area is being surface inspected by a crew of five people. Prior to their being sent out it was experimentally determined that they can detect artifacts up to five metres away (*W* = 5). This gives a Sweep Width of 10 metres (*2W*). They arbitrarily use a Sweep Spacing of 20 metres. The search covers half the project area. By noting that what is involved is a calculation for a fractional area (that is the Sweep Widths (*2W*))

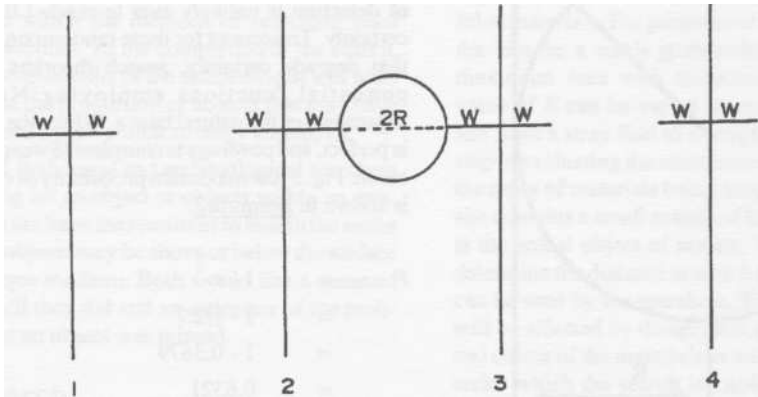


FIGURE 2

Possible encounter situation with a site defined by a circle. *W* = range at which material can be detected. *2W* = Sweep Width. Distance between numbered columns = Sweep Spacing. In this example, Sweep Spacing = *2W* + *2R*.

multiplied by track length (L) divided by total area (A)), we can simplify the calculation by using the fractional area covered by the inspection. For example, we can suggest a situation in which only half of the area was inspected using the 20 metre Sweep Spacing.

Assuming there is at least one of the target items in the project area, it is clear that *even* if Sweep Widths touch, the maximum probability of detecting the item would be 0.5, as only half the project area was searched.

Since Sweep Widths do not overlap, that is only a fraction of a fraction of the area was searched, the probability of detection is less than 0.5. We can use the fractional area Formula (Formula 5) with $W = 5, S = 20, A = 0.5$:

$$\begin{aligned}
 P &= (10/20) \times 0.5 \\
 &= 0.5 \times 0.5 \\
 &= 0.25
 \end{aligned}$$

Recall that Formula 5 is not exponential and thus gives a maximum probability of detection. To account for the usual field problems of surface inspection we would employ Formula 6:

$$\begin{aligned}
 P &= 1 - e^{-[(2WL)/s] [A]} \\
 &= 1 - e^{-[(2 \times 5)/20][.5]} \\
 &= 1 - e^{-[(10/20)][.5]} \\
 &= 1 - e^{-[.25]} \\
 &= 1 - .7788008 \\
 &= .2211992
 \end{aligned}$$

It should be repeated that the search illustrated here is, in fact, concerned with finding a single item in a large space rather than a cluster of items in a small area within a large space. As an archaeological site can be anything from a single stray item to a collection of items to a site containing monumental architecture, a site may be said to be found when an item, such as a chipped stone tool, is found.

Once the detection range has been established, the Sweep Spacing is the critical value controlling the probability of detection. In setting up the Sweep Spacing, the researcher begins to establish certain "thresholds of visibility" for archaeological materials within the project area. In a search for Late Woodland villages, for example, a Sweep Spacing of several tens of metres would probably be adequate but the "threshold of visibility" for small sites may approach zero. Ideally, prior knowledge should allow archaeologists to estimate the nature of the materials of the target site. From this they can estimate the detection ranges appropriate to the project.

Once detection range is determined, the size of the target artifact distribution is used to determine the probabilities of detection for various Sweep Spacings. The goal in adjusting Sweep Spacing is to bring at least one detector within detection range. This can be done by adjusting the Sweep Spacing so that in the worst case the swept area of a site multiplied by the artifact density is equal to or greater than 1.0. Thus, on a site with an assumed artifact density of 0.1 artifacts/sq.m, the Sweep Spacing must be set to sweep at least 10 square metres of the site so that one artifact will be brought within detection range of the searchers.

In the case of searching a completely unknown area, Sweep Spacing should be set quite small so as to maximize the chances of finding a single artifact. When enough data have been collected for trends to be detected, adjustments can be made to make

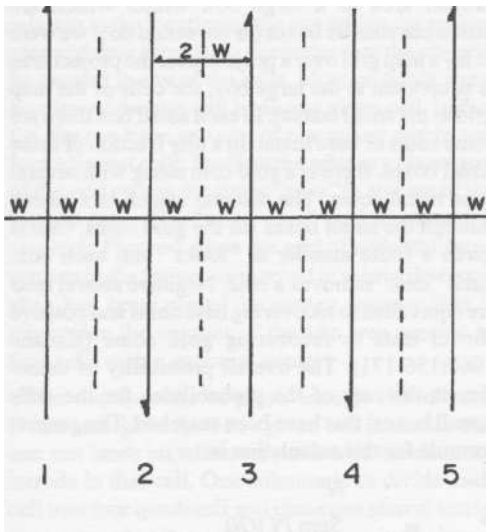


FIGURE 3 Search where Sweep Widths touch. Numbered columns (solid lines) are paths, dashed columns are the limits of detection range.

the search strategy as effective as possible within the practical limitations of the project.

Evaluating the Discrete Search

In the Discrete Search, the searching effort is applied in a discontinuous fashion, as in shovel testing. The detector is moved to a series of discrete points and the range of detection is so small that the detector can detect targets only very close to those points. This type of search is used when the target is in a medium where continuous search is not possible. For our naval commander this would be the case in which submarines are submerged and beyond the range of his shipboard sonar. In this event he might dispatch helicopters to drop sonobuoys, each of which searches a small volume of the ocean. In archaeology the analogous situation is encountered if cultural material is completely under the surface of the ground, or the ground itself is obscured by vegetation.

As with the continuous search, the basic criteria of evaluation are the variables of detection range, searched area and project area. And, as with the continuous search, there are three fundamental and inter-related considerations:

- 1 The probability of a site being in the area searched. In the worst case of "blind" search, it assumed there is at least one site in the area.
- 2 The probability that the detector will detect the target if it is brought within detection *range* of the target.
- 3 The fraction of the project area actually searched.

As with continuous search, evaluation of discrete search begins with defining the nature of the target archaeological materials, the probable size of the clusters they are expected to form (i.e. the area or volume of the type of site being sought), and the density of the material within the cluster. Density of material is used to compute the effectiveness of the detector; site area is used to compute the probability the detector will actually land within the perimeter of the cluster.

We are looking for a site, a location of human activity. In simplest terms, this means that artifacts are not uniformly distributed over the project **area** but are in clumps called sites. There is the special case of the so-called stray find which will serve as a useful demonstration.

Suppose we search in a one kilometre square in which there is one projectile point. To simplify the

calculation, it will be assumed that shovel tests extend to the bottom of any stratum that might contain cultural material. Shovel tests are assumed to be approximately 0.33 metres on a side which gives an area of 0.1089 square metres per shovel test. This means that there are 9,182,736.5 shovel tests possible in the kilometre square. Thus the raw probability of detection for any search for any series of randomly distributed artifacts is the number of artifacts multiplied by the probability of detection for a single shovel test. For example, if we assume that 50 artifacts are randomly distributed in our one kilometre square, then we calculate the following probability for detection by a single randomly placed shovel test:

$$P = 50 \times (1/9, 182, 736.5) \\ .000005445$$

Here one begins to see the limitations of the discrete search. In the description of continuous search one can actually design and analyze a search for a single artifact. Actual distribution of the material does not really make any difference except as the researcher wishes to adjust the Sweep Spacing in the expectation of finding a particular kind of site. With discrete search the entire analysis depends on first defining a locus of material, a "target site".

This problem is easy to visualize if we treat the project area as a large box within which are numerous smaller boxes (as we would do if we were to lay a map grid over a project area: the project area is equivalent to the large box, the cells of the map grid to the small boxes). In each small box there are some coins of base metal. In a tiny fraction of these small boxes, there is a gold coin along with several base metal coins. The discrete search is a search through the small boxes for the gold coins. One is given a finite number of "looks" into each **box**. Each "look" removes a coin. Negative shovel tests are equivalent to recovering base coins and positive shovel tests to recovering gold coins (Kadane 1968:156-171). The overall probability of detection is the sum of the probabilities for the cells (small boxes) that have been searched. The general formula for this calculation is:

$$P = \sum_{i=1}^N P_i (Q_i)$$

(Stone 1975:4-5)

where P_i is the probability of the target being in the cell i and Q_i is the probability of the i th look within that cell detecting the item.

To illustrate the analysis of discrete search we will consider a search for a small hunting camp site. Such a site is common in northeastern North America, and also represents a difficult target to detect. We will assign it a size M , which can be a site area or volume (see below). It lies within a project area of size A . It contains T artifacts and thus has an artifact density of T/M .

A preliminary grid can be established by making the individual cells in the grid equal to the area of the site. Thus the number of cells in the grid is found by dividing the site size into the project area: A/M . Making this a blind search with no prior knowledge of the area, it is assumed there is at least one site in the project area. M must necessarily be guessed and it is recommended that it be as small as possible and the grid cells be adjusted initially to the smallest size compatible with the means available to the project.

To find the site, shovel tests must be excavated in the cell which contains the site. It might seem that the problem of putting a detector (shovel test) within the assumed site would be solved by putting one shovel test in the centre of each cell of our grid, the cells of the grid being equal in area to the target site. But the placement of the grid is arbitrary in relation to the location of the site within the project area and thus there is no guarantee that the site will be centred in any of the cells. Most probably some fraction of the site will be in any given cell. In fact the site can have any sort of placement within any four adjacent cells. In effect the arbitrary placement of the grid causes the site to "pass" in and out of the various cells. The "worst case" grid placement is shown in Figure 4. Here the grid of cells (the large squares in the figure, each equal in area to the target site) has been placed in such a manner that it minimizes the amount of the site area present in four cells with a common corner.

The searcher has to place enough shovel tests ("take enough looks") in a given cell to ensure that one test lands on whatever portion of the site may intrude in that cell. One solution is to divide each cell into four quadrants and place one shovel test in the centre of each quadrant, as shown in the lower right cell in Figure 4. Each cell will require four "looks" to ensure that the site is not present in that cell.

Different placements of the grid would result in different fractions of the site protruding into any

given cell. This would seem to require more shovel tests within a cell to maximize the probability of placing a test on the site area within the cell. However, as more of the site "passes" out of one cell, more of it will protrude into an adjacent cell, and therefore more shovel tests in adjacent cells are likely to land on the site. If less than 25% of the site area is within a given cell, that cell is effectively empty. This is an admittedly rare occurrence, but we are posing a "blind search" and will assume the worst case.

Assuming the detector lands on the portion of a cell containing part of the site, the next concern is calculating the probability of the detector actually recovering material, that is, actually detecting the site. In the case of shovel testing, this probability depends on the volume of the individual shovel tests multiplied by the artifact density. Ideally this should approach certainty on sites with a high density of artifacts. But since a variety of random factors can degrade the effectiveness of a particular shovel test, the exponential function e is introduced once again (Stone 1975:301). The probability of detection for a single test is given by raising e to the expected number of artifacts per volume shovel test (EV):

$$P = 1 - e^{-EV}$$

The overall probability of detecting the site is found by multiplying the probability of the detector landing on the site by the probability of the detector recovering material if it lands on the site.

To return to our hypothetical hunting camp site with an area of size M : conditions of the survey require that a discrete search be employed to search for a target site of area M and an artifact density of D . Time, funds and crew size allow for E shovel tests to be excavated. (The values of M and D are estimates on the part of the investigator.)

The first task is to establish a preliminary grid of cells within which the search will be carried out. This is done by dividing the project area by the site area (A/M). Applying the 25% "worst case" rule to adjust for the grid's arbitrary placement with respect to the site, we derive the minimum probability that a shovel test will land on the site:

$$P = [E(A/M)] \times .25$$

If a shovel test lands on the site, the value EV equals artifact density multiplied by excavated volume: $D[V]$.

The overall probability of detection for the site is found by multiplying the "hit" probability by the "detector" probability:

$$P = [E/(A/M) \times .25] \times 1 - e^{-D[V]}$$

It quickly becomes apparent that unless the site is large or the density of material is high, discrete search methods are likely to be unproductive and expensive.

To illustrate this last point, let us reconsider our hypothetical site and insert into the equations general values derived from sites found during cultural resource surveys conducted in upstate New York. We will assume a small-scale survey involving the investigation of one square kilometre. Previous experience in the region shows that the smallest site which may be considered significant to the agency that oversees the project has a diameter of about 15 metres and an artifact density of 0.28 per square metre of surface area. These will be the characteristics of the target site. In north-eastern North America most materials recovered from such sites are found in a layer no more than 0.33 metres deep. Shovel tests are about 0.33 m on a side and carried to the subsoil, which gives a volume of 0.0359 cubic metres per shovel test. Since a square metre of surface area represents 0.33 cubic metres of earth which might contain artifacts, a surface density of 0.28 artifacts per square metre yields a volume density of 0.856 artifacts per cubic metre.

From these target site values the following calculations can be made:

1. Site area = $Pi (r^2)$
 $= Pi \times 7.5^2$
 $= 177m^2$
2. Number of cells in Grid = A/M
 $= 1 km^2/177m^2$
 $= 1,000,000/177$
 $= 5650$
3. Number of shovel tests = E
4. The worst case probability of a shovel test landing on the site if the site is in the cell = 0.25
5. Probability of recovering material in a shovel test on the site =
 $= \frac{-(0.856 \times 0.359)}{1 - e}$
 $= 0.0312$

6. Overall probability of detection (P):
 $= [(E/5650) \times 0.25] \times 0.0312$

7. If we put one shovel test in the centre of each cell then the probability of detection is:

$$P = [(5650/5650 \times 0.25) \times 0.0312]$$

$$= 0.25 \times 0.0312$$

$$= 0.0078$$

This worst case is likely to happen only 9% of the time. Comparison of the relationship between the site defined by the circle and the square of the same area shows that 82% of the time the grid will be so placed as to put one shovel test on the site. This value can be substituted for the 0.25 in Step 4, above, and this raises the overall probability of site detection to 0.02584 in the above example.

It is clear that shovel tests are poor detectors of sites with a low artifact density and this has to be compensated for by increasing their number to a level commensurate with the detection probability desired by the researcher. Suppose that, in the example just given, the desired detection probability is 50%. The required number of shovel tests in a worst case situation would be:

$$E = [P/(.25 \times .03)] \times A/M$$

$$= [.5/0.0078] \times 5650$$

$$= 64.1025 \times 5650$$

$$= 36,2179.49$$

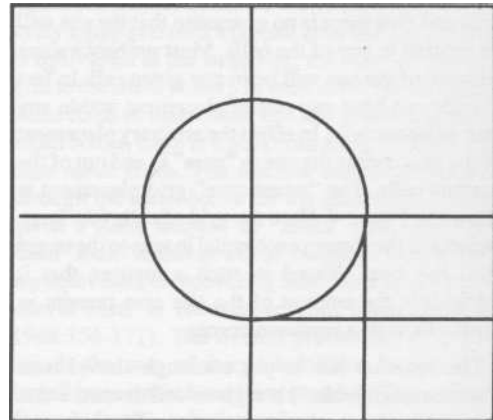


FIGURE 4 Worst-case position of search grid with respect to a site defined by the circle. The area of the circle is equal to the area of the larger cell. The quartered cell illustrates the number of subdivisions (looks) required to place a shovel test on the portion of the site protruding into the cell.

In the average situation however the required number of shovel tests would be 109,326.63. In one square kilometre this comes to one shovel test every 2.76 square metres (or a shovel test interval of 1.66 metres) for the worst case, and one shovel test for every 9.146 square metres (or a 3.02 metre interval) in the general case.

As with continuous search the researcher has the obligation to establish thresholds of visibility of interest to him. Detection probabilities can be calculated based on the values E can take under the constraints of time, crew and budget imposed on any particular project. Through a process of iteration the researcher can create graphs of the detection probabilities for any combination of values for the variables.

To summarize this example: the first step in evaluating the discrete search was to correct for the arbitrary placement of a map grid and its effect on the probability of the target site being within any given cell within that grid. From that correction computations of the probability of detection were made based on the number of tests placed within that cell. We have performed our calculations on the assumption that the entire project area was tested.

Estimate of the Universe from the Sample

Archaeological surveys should be able to estimate realistically the nature of the site universe from which the sample of discovered sites was drawn. If one can estimate accurately the probability of finding a site of any given size and density of material, then it is not hard to estimate the proportion which sites with those characteristics represent out of the total of such sites in the project area. In short the probability of detection can be used as an estimator of the universe of sites within the boundaries of the project area.

For example, in discrete search one is searching a one kilometre square and a worst case evaluation gives a probability of 0.2 for detecting a site of type Y. If five such sites are found, it is not unreasonable, assuming topographic factors, etc. have been controlled for, to say that there could be as many as 25 such sites in the project area.

With continuous search the same principles hold except that it is so easy to approach 90% efficiency with continuous search that site detection using that technique seems a near certainty. In that case, the sample of detected sites will be nearly equal to the

total number of sites actually within the project area.

If one can indeed evaluate a survey and provide a good estimator of efficiency, then the question of what constitutes an adequate sample raises itself. There is no general solution to this question. King has suggested that a 50% sample may be necessary for some situations (King 1975:163) while others such as Plog feel that a 2% sample may allow regularities in the data to be detected (Plog 1982:192). There may be no general solution to this question and determinations of adequacy will have to be based on the nature of the data base and ongoing research in the region involved.

With particular regard to contract work, I suggest that the evaluative techniques presented here will make it much easier for archaeologists and contractors to find a common ground for communication. If the contractors can be shown that specific levels of adequacy are being met it may be much easier to continue funding. Moreover, with more accurate estimators of the site universe, questions of "significance" or culture process may be addressed more rigorously.

Conclusion

The techniques presented here have been particularly directed to those engaged in contract work but are obviously applicable to any problem for which archaeological survey is conducted. The aim of the paper has been to show general operational principles that can be applied to particular *survey* problems.

These methods offer archaeologists the ability to estimate time and cost requirements for given levels of detection that are mathematically and experimentally defensible. The need to define properly the characteristics of objects of the search should lead to thorough formulations about the problems being investigated and the goals of any search undertaken to address these problems.

These evaluations can be done before or after survey. Ultimately they rest on the nature of the materials being sought. In discrete search especially, it is important to realize that the definition of the target sites is critical to solving the detection function. This may seem inconsistent with the idea of a blind search. For this reason it seems that the best way to use these methods is to do a series of iterations to give a range of detection probabilities for a range of sites with various areas and artifact densities.

It should also be borne in mind that these evaluative methods do not constitute a "fire and forget" system. Constant monitoring of the progress of any survey will always be necessary. Data acquired during the course of work may indicate necessary revisions in the allocation of search effort in order to meet research or project goals. It is critical that the characteristics of sites being discovered be compared with the pre-survey estimates of target site parameters. This is especially true with the discrete search which, due to its limited detection utility, needs to be constantly monitored to maximize any possible returns.

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