MEASURING
&
MONITORING
Plant Populations

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and rebar) can be expensive and awkward to pack long distances. The markers used to permanently mark sampling units are susceptible to loss or damage from such things as vandalism, animal impacts, and frost-heaving. Duplication of markers and back-up methods of relocating permanent sampling unit locations can help with this problem but can be very time-consuming.

Even when the markers are still in place, they may be difficult to find. Metal detectors and global positioning units can help you find the markers, but these add costs and field time. If frequency quadrats and points are the permanent sampling units, and you are positioning these at systematic intervals along transects, you must ensure the quadrats or points are repositioned as close as possible to the positions in the year in which the study was set up. This is especially critical for small frequency quadrats when the rooted portion of the target species is small and for points when the cover of the target species is likely to be sparse. Permanently monumenting not only the transect ends but also intermediate points in between and carefully stretching the tape at each measurement period can help to ensure the transect is in the same location. For frequency quadrats you can also monument two corners of each quadrat using large nails. This adds additional insurance but also results in more labor.

Impacts either from investigators or from animals may bias your results. By going back to the same sampling unit locations each year, you might negatively impact the habitat in or near the permanent sampling units. In addition, permanent markers may also attract wildlife, domestic livestock, wild horses, or burros. This might lead to differential impacts to the vegetation in or near the sampling units. If markers are too high (for example, t-posts or other fence posts), livestock may use the markers for scratching posts and differently impact the sampling units. Wildlife impacts may also occur. Raptors, for example, might use the markers as perches; this could result in fewer herbivores in the sampling units than elsewhere in the target population, with resulting differences in the plant attribute being measured. Using shorter markers, such as rebar no greater than 0.5m high, will at least partially resolve this problem (but see below for safety concerns).

Permanent markers are not feasible in some situations because of the nature of the habitat or for safety reasons. For example, sand dune systems do not lend themselves to the use of permanent markers because drifting sand can quickly bury the markers. You wouldn't want to use permanent steel posts or rebar in areas frequented by off-road vehicles because of the risk to human life.

Another disadvantage of a design using permanent sampling units is that you usually need 2 years of data to determine adequate sample size. The only exception to this is when you have some basis to estimate the degree of correlation (the correlation coefficient) of sampling units between years when estimating means (e.g., density sampling) or a model of how the population is likely to change when estimating proportions (e.g., frequency sampling). We'll discuss this at more length in the next section.

G. How Many Sampling Units Should Be Sampled?

An adequate sample is vital to the success of any successful monitoring effort. Adequacy relates to the ability of the observer to evaluate whether the management objective has been achieved. It makes little sense, for example, to set a management objective of increasing the density of a rare plant species by 20% when the monitoring design and sample size will not likely detect changes in density of less than 50%.

1. General comments on calculating sample size

Deciding on the number of sampling units to sample (which we refer to as "sample size") should be based on the following considerations:

a. Sample size should be driven by specific objectives

If you are targeting point-in-time estimates (parameter estimation), you need to specify how precise you want your estimates to be. If you are trying to detect changes in some average value, you need to specify the magnitude of the change you wish to detect and the acceptable false-change and missed-change error rates (refer to Chapter 6 for further guidance).

b. Sample size should be based on the amount of variability in actual measurements

You should assess this variability during pilot sampling. Once you have tried various sampling unit sizes and shapes and have decided upon a particular one, start randomly positioning the sampling units in the population. After you have sampled some initial bunch of sampling units, stop and do some simple number-crunching with a hand calculator to see what the variation in the data looks like. You can plug standard deviations into sample size equations or computer programs, and the output will inform you as to whether you have sampled enough. If you haven't, sample size equations (or a computer program) will calculate the number of sampling units you need to sample in order to meet your objective. We discuss the process of sequential sampling in detail below.

c. Assumptions of formulas and computer programs

The sample size formulas and computer programs assume that the sampling units are positioned in some random manner and that a distribution of sample means (a sampling distribution) from your population fits approximately a normal distribution. If your population is highly skewed, this latter assumption will not be true for small sample sizes. We discuss this issue in more detail in Chapter 11.

d. Infinite vs. finite populations

We introduced this concept in Chapter 5. Most computer programs and standard sample size equations assume that the population you are sampling from is infinite. This will always be the case if you are estimating cover using either points or lines, because these are considered dimensionless. If, however, you are sampling a relatively small area, and you are making density, frequency, cover, or biomass assessments in quadrats, then you should account for the fact that you are sampling from a finite population. This means there is some finite number of quadrats that can be placed in the area to be sampled.

The sample size formulas provided in Appendix 7 include a correction factor called the Finite Population Correction (FPC). If you are sampling more than 5% of a population, applying the FPC "rewards" you by reducing the necessary sample size. In addition to describing how to apply the FPC to sample size determination, Appendix 7 also describes how to apply it to the results of two-sample significance tests. Appendix 16 shows how to use the finite population correction factor when sampling to detect a difference in proportions using permanent sampling units.

e. Relationship of sample size to precision level

Precision increases with sample size, but not proportionately. This is illustrated in Figure 7.29. For this example, the statistical benefits of increasing sample size diminish once you reach about *n*=30; any benefits to using more than 30 sampling units relate to adequately capturing the variability in the population being sampled. This also serves to highlight the most important aspect of good sampling design: you should seek to increase statistical precision and power not by simply increasing sample size, but by reducing the standard deviation to as small a value as possible.

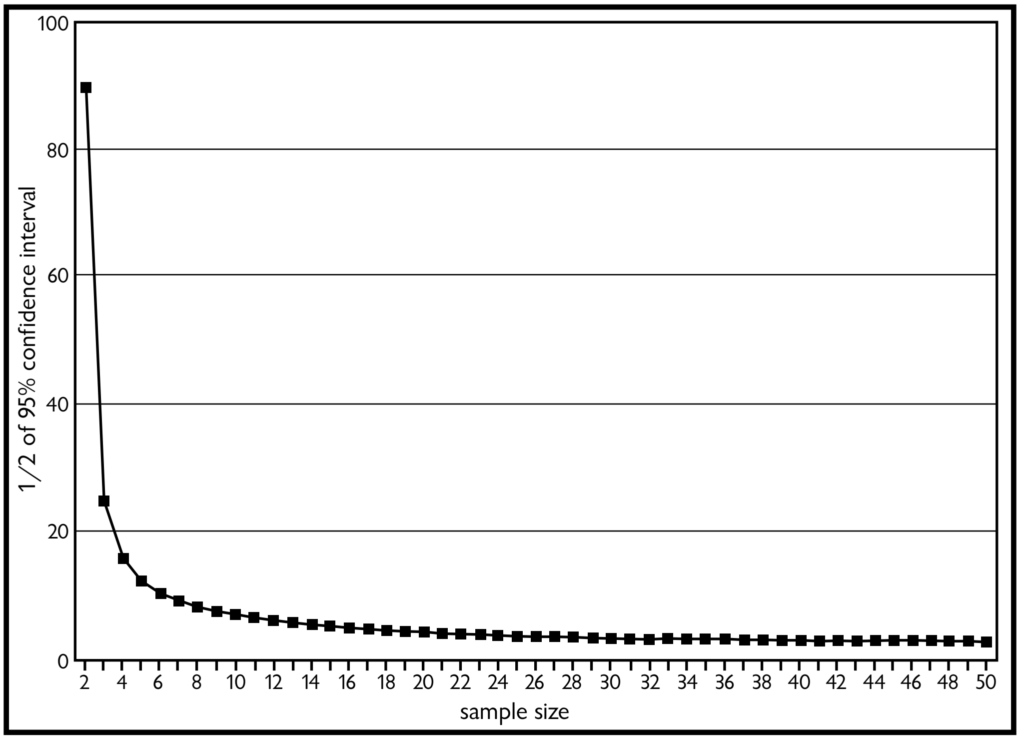


FIGURE 7.29. Influence of sample size on level of precision. Sample sizes necessary to achieve different levels of precision at a constant standard deviation of 10. Note that there is no effective improvement in precision after about n = 30.

f. Problems with some sample size formulas

Most formulas that are designed to determine sample sizes for "point-in-time" estimates (parameter estimation) with specified levels of precision do not account for the random nature of sample variances. They do not include a "level of assurance" (also known as a tolerance probability) that you will actually achieve the conditions specified in the sampling size equations and obtain a confidence interval of a specified width. Blackwood (1991) discusses this topic in lay person's terms and reports the results of a simulation that illustrates the concept. Kupper and Hafner (1989) provide a correction table to use with standard sample size equations for estimates of single population means or population totals. A modified version of this table and instructions on how to use it are included in Appendix 7.

2. Information required for calculating sample size

Appendix 7 gives equations for calculating sample sizes for the following sampling objectives: (1) estimating means and totals; (2) detecting change between two time periods in a mean value; (3) detecting differences between two means when using permanent sampling units;

(4) estimating a proportion; and (5) detecting change between two time periods in a proportion using temporary sampling units. Appendix 16 gives directions for using the computer programs STPLAN and PC SIZE: CONSULTANT to calculate sample sizes to meet all of these objectives (except estimating a proportion) and, in addition, gives instructions on calculating the sample size required to detect change between two time periods in a proportion when using permanent sampling units (these programs are discussed further in Section H). Both appendices include completely worked-out examples. The following discussion briefly summarizes the information required to use either the equations or computer programs to calculate sample size.

Estimating means and totals. You must specify the precision desired (confidence interval width), the confidence level, and an estimate of the standard deviation.

Detecting change between two time periods in a mean value. You must specify the false-change error rate, the power of the test, the magnitude of the smallest change you wish to detect, and an estimate of the standard deviation (the population standard deviation is usually assumed to be the same for both time periods).

Detecting change between two means using permanent sampling units. You must specify the false-change error rate, the power of the test, the magnitude of the smallest change you wish to detect, and an estimate of the standard deviation (this is the standard deviation of the differences between the paired sampling units, *not* the standard deviation of the population being sampled in the first year).

Estimating a proportion. You must specify the precision desired (confidence interval width), the confidence level, and a preliminary estimate of the proportion to be estimated (if you don't have any idea of what proportion is to be expected you can conservatively estimate the sample size by assuming the proportion to be 0.50).

Detecting change between two time periods in a proportion using temporary sampling units. You must specify the false-change error rate, the power of the test, the magnitude of the smallest change you wish to detect, and a preliminary estimate of the proportion in the first year of measurement (using a value of 0.50 will conservatively estimate the sample size).

Detecting change between two time periods in a proportion using permanent sampling units. You must specify the false-change error rate, the power of the test, the magnitude of the smallest change you wish to detect, and an estimate of the sampling unit transitions that took place between the two years.

Your management and sampling objectives already include most of the information required to calculate sample size using either the equations of Appendix 7 or the computer programs STPLAN and PC SIZE: CONSULTANT, following the instructions of Appendix 16. What is missing is an estimate of the standard deviation for those situations where you wish to estimate a mean value or detect change between two mean values and a preliminary estimate of the population proportion when estimating a proportion or detecting change between two proportions using temporary sampling units. For proportions you have the flexibility of simply entering 0.50 as your preliminary estimate of the population proportion and calculating your sample size based on this. Alternatively, you can use an estimate derived from pilot sampling. When dealing with mean values, however, you must have an estimate of the standard deviation. This is the subject of the next section. (Detecting change between two time periods in a proportion using permanent sampling units is a special case that will be discussed separately below and in Appendix 18.)

3. Sequential sampling to obtain a stable estimate of the mean and standard deviation

In several places in this chapter we have stressed the need for pilot sampling. The principal purposes of pilot sampling are to assess the efficiency of a particular sampling design and, once a particular design has been settled upon, to assist in determining the sample size required to meet the sampling objective. Pilot sampling enables us to obtain stable estimates of the population mean and the population standard deviation. By dividing the sample standard deviation by the sample mean we get the coefficient of variation. Comparing coefficients of variation enables us to determine which of two or more sampling designs is most efficient (the lower the coefficient of variation, the greater the efficiency of the sampling design). The estimate of the standard deviation derived through pilot sampling is one of the values we use to calculate sample size, whether we use the formulas of Appendix 7 or a computer program.

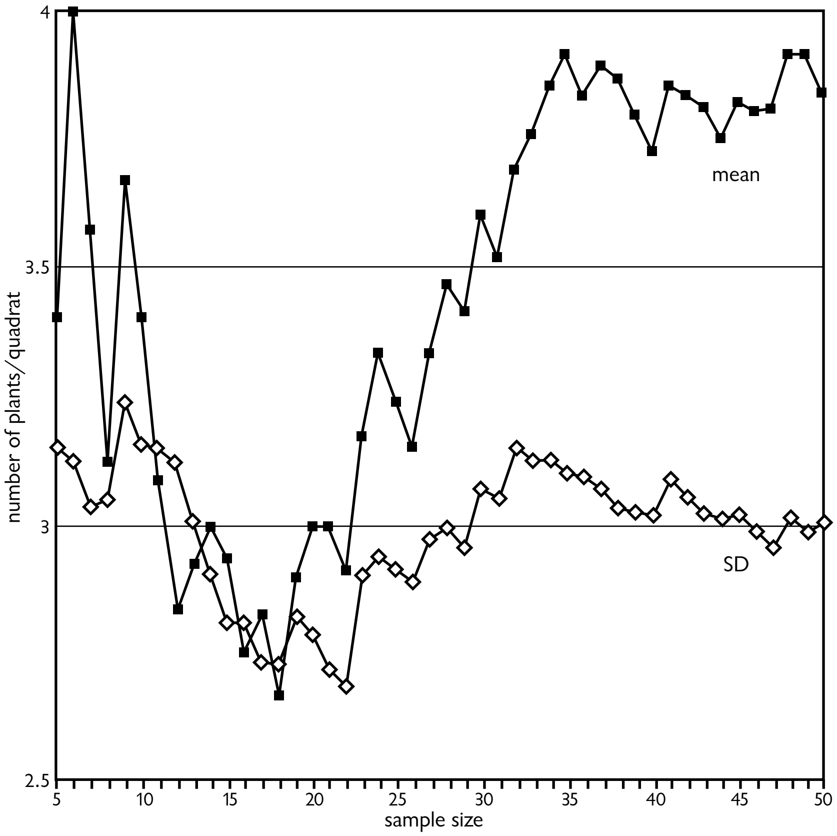
Sequential sampling is the process we use to determine whether we have taken a large enough pilot sample to properly evaluate different sampling designs and/or to use the standard deviation from the pilot sample to calculate sample size. The process is accomplished as follows.

Gather pilot sampling data using some arbitrarily selected sample size. The selection of this initial sample size will depend upon the relative amount of variation in the data—if many of the sampling units yield numbers similar to one another, then you may want to perform the first sequential sampling procedure after $n = 8$ or 10. If there is a lot of variation among the sampling units, then you may want to start with a larger number (e.g., $n \geq 15$), or consider altering the size and/or shape of your sampling unit prior to doing the first iteration of the sequential sampling procedure.

Calculate the mean and standard deviation for the first two quadrats, calculate it again after putting in the next quadrat value, and then repeat this procedure for all of the quadrats sampled so far. This will generate a running mean and standard deviation. Look at the four columns of numbers on the right of Figure 7.30 for an example of how to carry out this procedure. Most hand calculators enable you to add additional values after you've calculated the mean and standard deviation, so you don't have to re-key in the previous values.

Plot on graph paper (or use a computer program as discussed later) the sample size vs. the mean and standard deviation. Look for curves smoothing out. In the example shown in Figure 7.30, the curves smooth out after n=35.

In graphing your results beware of y-axis scaling problems. If your first few quadrats are very deviant from each other, you may scale your y-axis with too broad a range, which will give a false impression of the lines smoothing out. The top and bottom graphs of Figure 7.31 both graph the same data set (only the order of the data was changed). Because the first few quadrats in the upper graph contained large values, the scale of the y-axis was set from 0 to 7. The result is that there appears to be a smoothing out of the curves at around 15 quadrats. In the bottom graph, the first few quadrats contained smaller values, so the scale of the y-axis was set from 0 to 2.5. This graph gives a much clearer view of the true situation: the



running means and standard deviations

n	plants	mean	SD	n	plants	mean	SD
1	1	1.00	0.00	26	1	3.15	2.88
2	2	1.50	0.50	27	8	3.33	2.97
3	0	1.00	0.79	28	7	3.46	3.00
4	9	3.00	3.52	29	2	3.41	2.95
5	5	3.40	3.15	30	9	3.60	3.07
6	7	4.00	3.12	31	1	3.52	3.05
7	1	3.57	3.04	32	9	3.69	3.15
8	0	3.13	3.05	33	6	3.76	3.13
9	8	3.67	3.24	34	7	3.85	3.13
10	1	3.40	3.16	35	6	3.91	3.10
11	0	3.09	3.15	36	1	3.83	3.09
12	0	2.83	3.12	37	6	3.89	3.07
13	4	2.92	3.01	38	3	3.87	3.03
14	4	3.00	2.90	39	1	3.79	3.03
15	2	2.93	2.81	40	1	3.73	3.02
16	0	2.75	2.80	41	9	3.85	3.09
17	4	2.82	2.73	42	3	3.83	3.06
18	0	2.67	2.73	43	3	3.81	3.02
19	7	2.89	2.82	44	1	3.75	3.02
20	5	3.00	2.78	45	7	3.82	3.02
21	3	3.00	2.71	46	3	3.80	2.99
22	1	2.91	2.68	47	4	3.81	2.96
23	9	3.17	2.90	48	9	3.92	3.02
24	7	3.33	2.94	49	4	3.92	2.99
25	1	3.24	2.91	50	0	3.84	3.00

FIGURE 7.30. A sequential sampling graph. Running means and standard deviations are plotted for increasing sample sizes. Note how the curves smooth out after n = 35.

curves have not really smoothed out even after 100 quadrats.[4] If early quadrat values are too extreme you may want to start plotting with *n*=5 rather than *n*=2 to avoid too great a y-axis range. The decision to stop sampling is a subjective one. There are no hard and fast rules.

A computer is valuable for creating sequential sampling graphs. Spreadsheet programs such as Lotus 1-2-3 and Excel enable you to enter your data in a form that can later be analyzed and at the same time create a sequential sampling graph of the running mean and standard deviation. This further allows you to look at several random sequences of the data you have collected before making a decision on the number of sampling units to measure. Figures 7.32 and 7.33 both show the results of sampling the entire "400-plant population" (introduced in Chapter 5) using a 0.4m x 10m quadrat size (the population is contained in a 20m x 20m macroplot; there are 100 possible quadrat positions in the population with this size quadrat). The only difference between these two graphs is the ordering of the data: the data were randomly reordered prior to creating each graph.

Figure 7.34 shows sequential sampling graphs where the number of sampling units gathered far exceeded the number where the curves flattened out.

[4] The sequential sampling graph at the bottom of Figure 7.31 illustrates a poor sampling design. Because 1m x 1m quadrats were used, most of the quadrats had 0 plants in them. Sampling several consecutive quadrats with 0 plants brings the running mean and standard deviation down until a quadrat is located with several plants in it. This brings the running mean and standard deviation up sharply (see the spikes on the graph). This phenomenon by itself should alert you to the fact that the sampling design is inadequate.

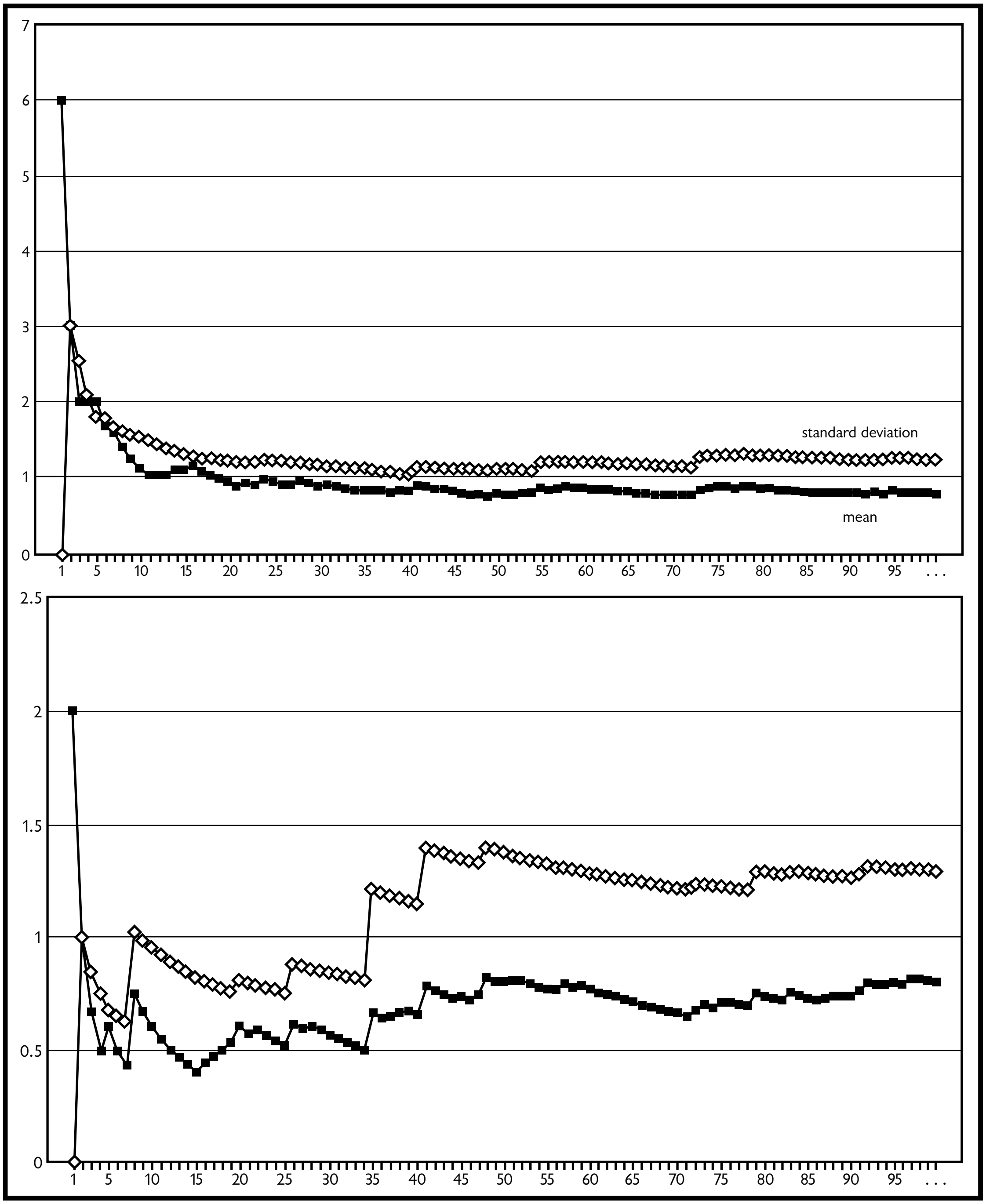


FIGURE 7.31. Sequential sampling graphs for Astragalus applegatei at the Euwana Flat Preserve. The upper graph shows what can happen when the y-axis is set at too large a range, because of initial large values. This can make it appear that the running mean and standard deviation has smoothed out when in fact they haven't. The bottom graph illustrates the real situation: neither statistic has smoothed out even by n = 100. This is a poor sampling design. See text for further elaboration.

If there are too many zeros in your data set, then sequential sampling graphs will not make sense. We saw this to some extent in Figure 7.31. A more extreme example is shown in Figure 7.35. Graphs like this should alert you to major problems with the sampling design.

Use the sequential sampling method to determine what sample size *not* to use (you don't use the sample size below the point where the running mean and standard deviation have not

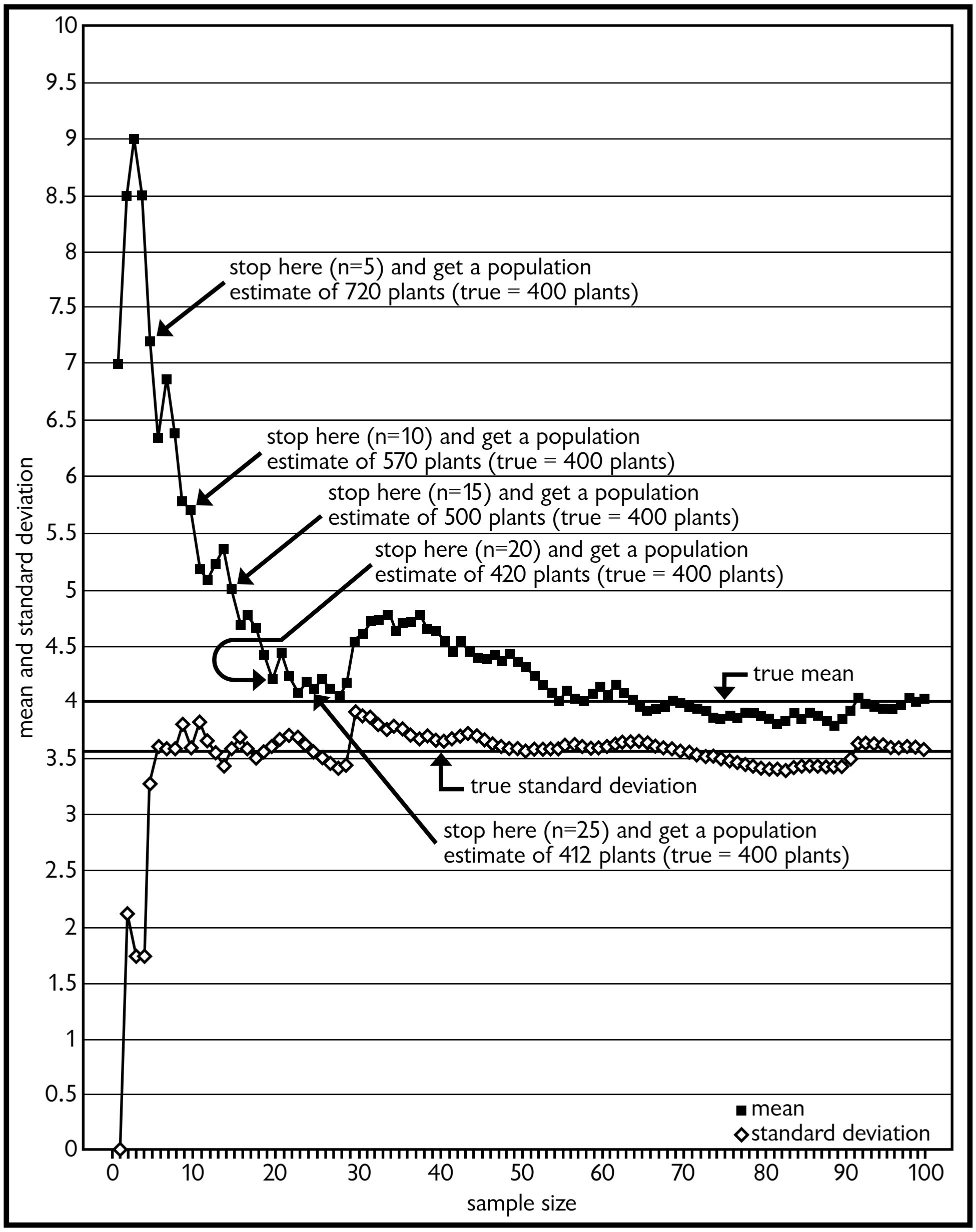


FIGURE 7.32. Sequential sampling graph of the 20m x 20m "400-plant population" introduced in Chapter 5. The population was sampled using a 0.4m x 10m quadrat. The entire population consists of 100 quadrats. Notice how far estimates are from the true mean value if they are made prior to the curves smoothing out.

stabilized). Plug the final mean and standard deviation information into the appropriate sample size equation or computer program to actually determine the necessary sample size.

4. Alternatives to sequential sampling to obtain an estimate of the standard deviation

Pilot sampling, using the sequential sampling procedure described above, is by far the best means of deriving an estimate of the standard deviation to plug into a sample size equation or computer program. There are, however, two other methods that will be briefly discussed.

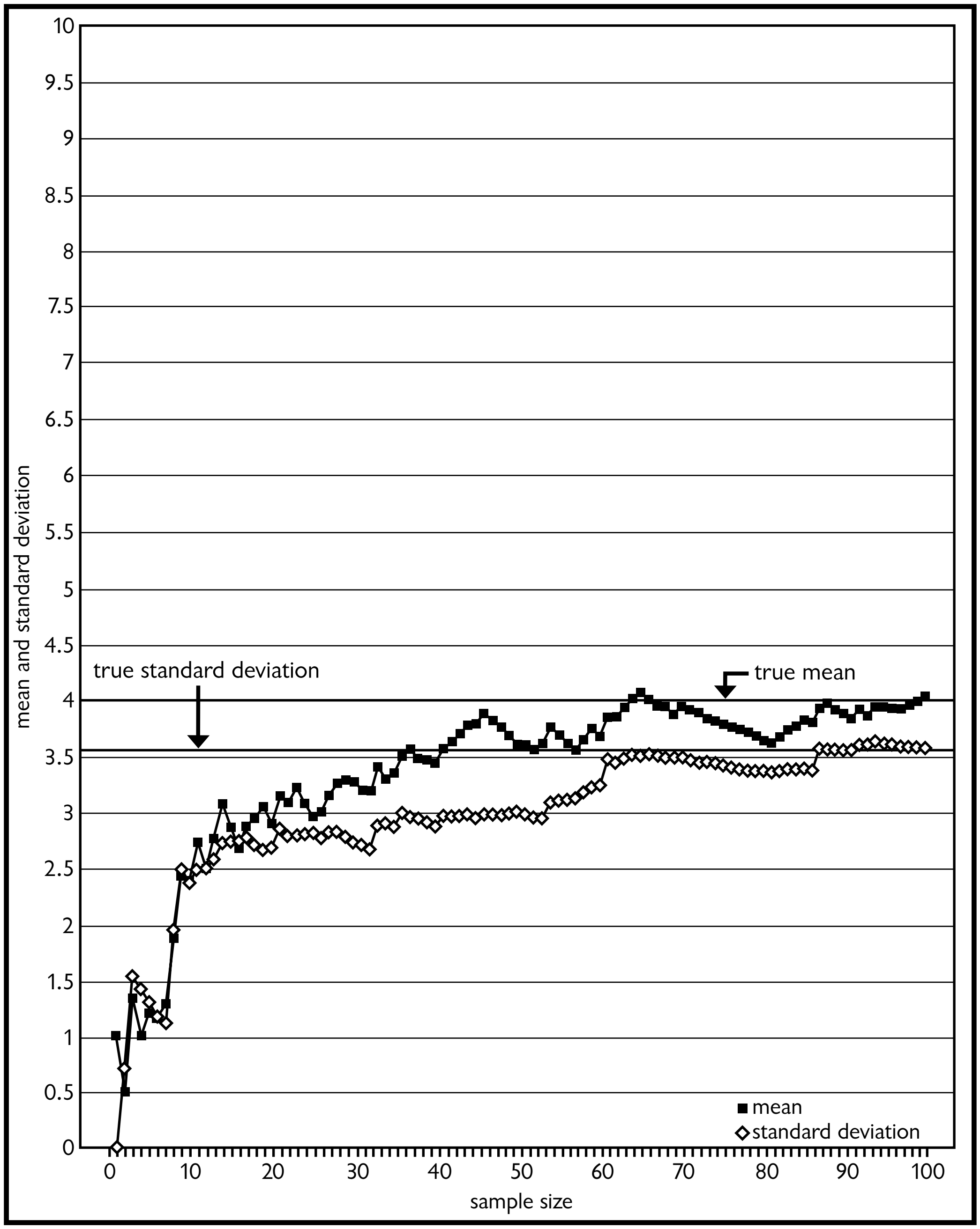


FIGURE 7.33. Sequential sampling graph for the 20m x 20m "400-plant population." Sampling unit size is the same as in Figure 7.32. The only difference between this graph and Figure 7.32 is that the data were randomly reordered. If we'd used the initial values shown in this graph (prior to the curves leveling off), we would have seriously underestimated the true mean value, as opposed to overestimating it as was the case in Figure 7.32.

a. Use data from similar studies to estimate the standard deviation

Although not as reliable as a pilot study, you may have conducted a study using the same study design, measuring the same vegetation attribute, and in the same vegetation type. The standard deviation of the sample from this study can be used as an estimate of the standard deviation of the population that is the focus of the current study.

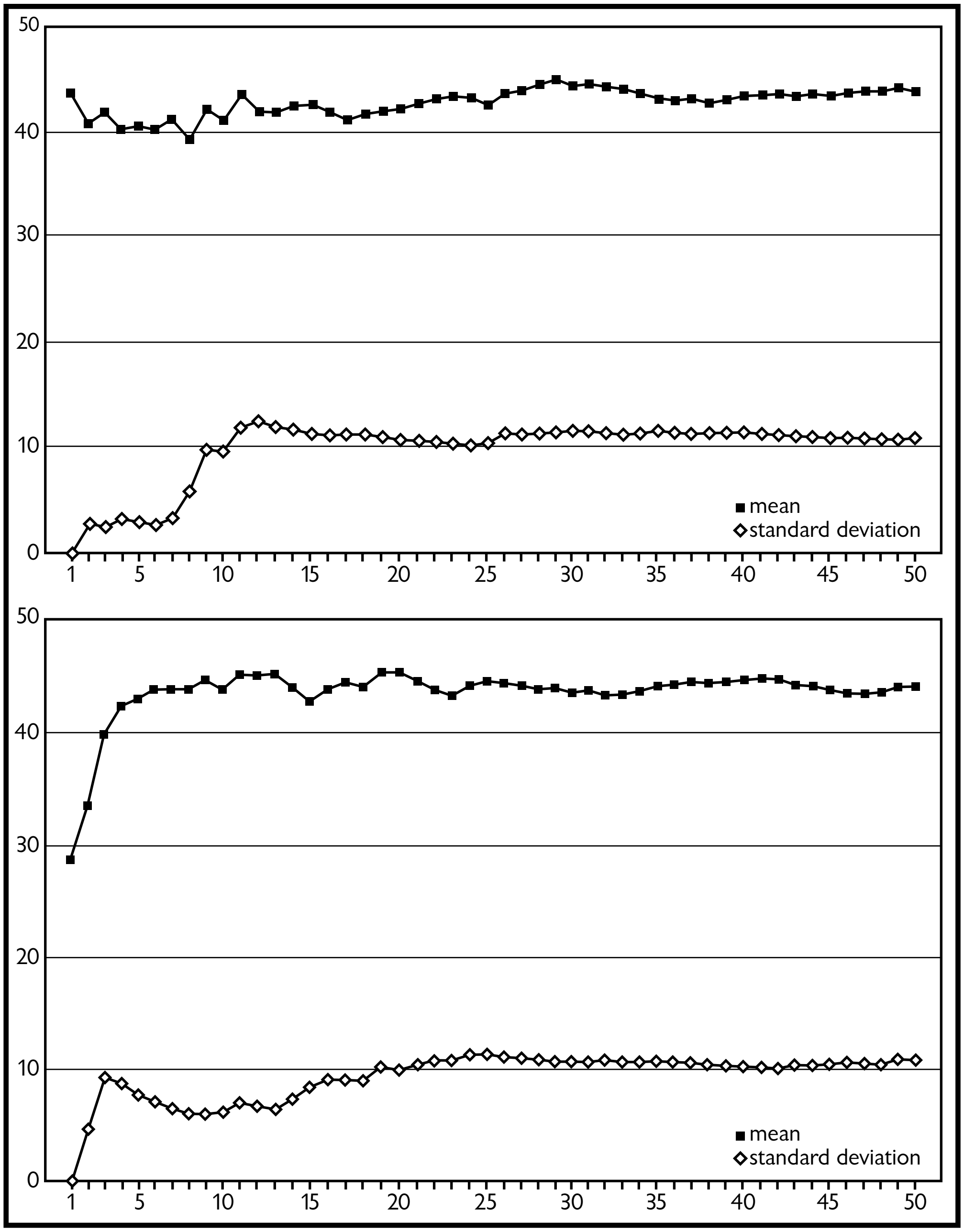
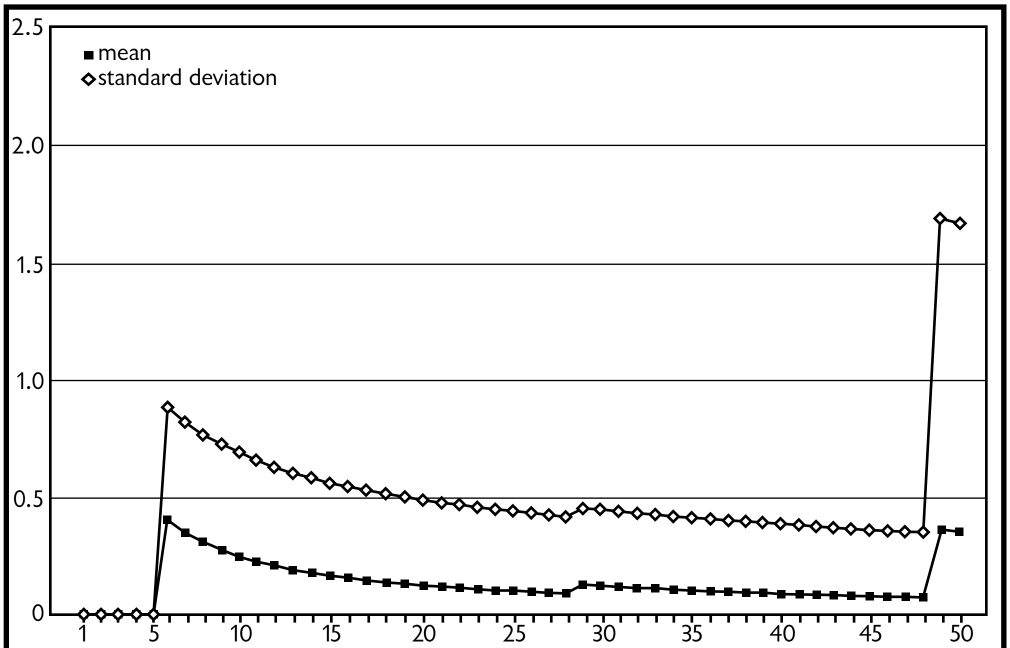


FIGURE 7.34. Sequential sampling graphs of vegetation height measurements at Mt. Hebo. These are graphs of the same data but in different orders. Note how the graphs have flattened out long before the sampling ended.

b. By professional judgment

As pointed out by Krebs (1989) an experienced person may have some knowledge of the amount of variability in a particular attribute. Using this information you can determine a range of measurements to be expected (maximum value - minimum value) and can use this to estimate the standard deviation of a measure. Table 7.5, adapted from the table in Dixon and Massey (1983), and reproduced in Krebs (1989), gives the appropriate conversion factor to be multiplied by the range value to come up with an estimate of the population standard deviation.



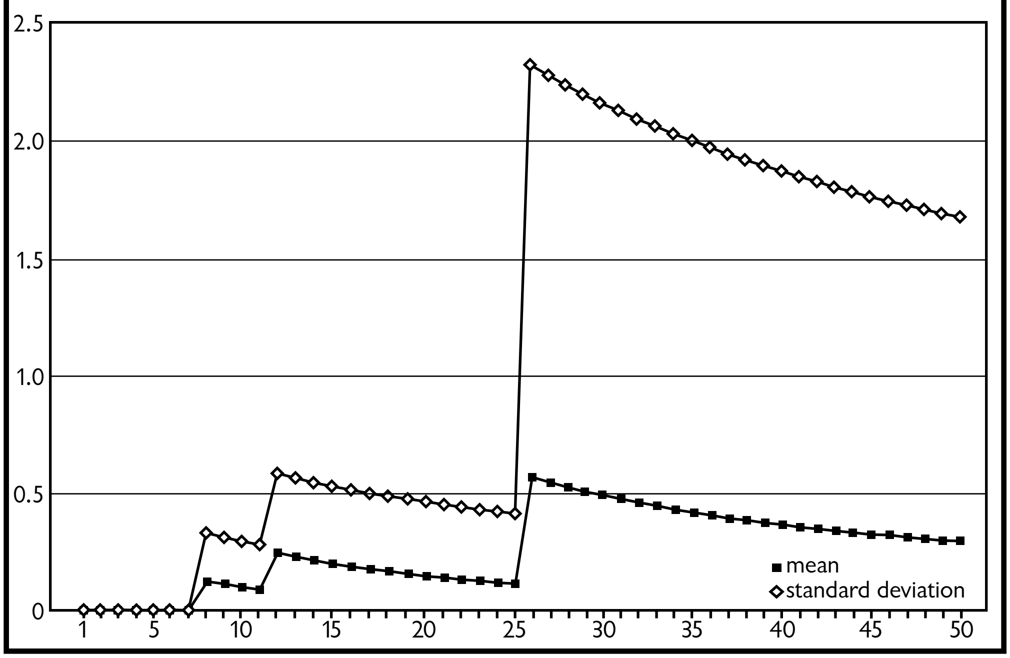


FIGURE 7.35. Sequential sampling graphs of bracken fern stem density at Mt. Hebo. Both graphs plot the same data set in different order. This is an example of a poor sampling design. Because 1m x 1m quadrats were used, most of the quadrats had 0 plants in them. Sampling several consecutive quadrats with 0 plants brings the running mean and standard deviation down until a quadrat is located with several stems in it. This brings the running mean and standard deviation up sharply and results in the spikes shown on the graphs. This pattern should alert you to the need to change your sampling design.

To illustrate how to use this table, let's assume we know from experience with the plant species we're working with that we expect, in a sample of size 30, a range of 0 plants per quadrat to 100 plants per quadrat (this process assumes a normal distribution so we'd better not have too many quadrats with 0's in them). The range in this case is 100 plants - 0 plants = 100 plants. The conversion factor for a sample of size 30 is 0.245. Our estimate of the population standard deviation is, therefore, 100 plants x 0.245 or 24.5 plants per quadrat.

Although this method *can* be used, it should be emphasized again that data from a pilot study are more reliable and are preferable to this method.

sample size	conversion factor	sample size	conversion factor
2	0.886	19	0.271
3	0.591	20	0.268
4	0.486	25	0.254
5	0.430	30	0.245
6	0.395	40	0.231
7	0.370	50	0.222
8	0.351	60	0.216
9	0.337	70	0.210
10	0.325	80	0.206
11	0.315	90	0.202
12	0.307	100	0.199
13	0.300	150	0.189
14	0.294	200	0.182
15	0.288	300	0.174
16	0.283	500	0.165
17	0.279	1000	0.154
18	0.275		

TABLE 7.5. Estimating the standard deviation of a variable from knowledge of the range for samples of various sizes. Multiply the observed range (maximum - minimum value) by the table values to obtain an unbiased estimate of the standard deviation. This procedure assumes a normal distribution. From Dixon and Massey (1983) and reproduced in Krebs (1989).

5. Estimating the standard deviation when using permanent sampling units

Estimating the standard deviation for a design that uses permanent sampling units is difficult because it is the standard deviation of the difference between the sampling units between the two years that must be plugged into the sample size equation or computer program, and this is a value that you will not have until you have collected data in two years. Thus, your pilot study must span two years before you can accurately estimate the sample size required to meet your sampling objective. You would like, however, to make a reasonable estimate from the first year's data of the standard deviation of the difference. This will give you a good chance of having used a large enough sample size the first year, with the result that you will not have to add more sampling units the second year and will be able to use the first year's data in your analysis. Following are some methods you can use for this purpose.

You can estimate the standard deviation using the alternative methods discussed under the section above. Remember, however, that it is the standard deviation of the difference that must be estimated, so if you use data from previous studies they must be studies that used permanent sampling units. If you use the expected range to estimate the standard deviation, it must be the range of the differences, not the range of the data for any one year.

There is another way you can calculate the necessary sample size by having only the first year's pilot data. This method requires that you have some knowledge of the degree of correlation (correlation coefficient) expected between the permanent sampling units between years. Sample Size Equation #3 in Appendix 7 gives a formula by which you can estimate the standard deviation of the difference between years by using the standard deviation of the first year's sample and the correlation coefficient. This is something you might have from similar studies on the same plant species (although in that case you'd probably already have an estimate of the standard deviation of the difference between years that you could use). Based on your knowledge of the life history of the species you are dealing with, you might make an initial estimate of correlation. For example, if you're monitoring a long-lived perennial and you don't anticipate a lot of seedling recruitment (or if you expect seedling recruitment to be very close to parent plants), you might estimate that the correlation coefficient between years is relatively high, say about 0.80 or 0.90. You then plug this coefficient into the formula, along with your estimate of the standard deviation of the first year's data.

Whichever method you use to estimate the standard deviation of the difference, once you've collected the second year's data, you will still need to plug the actual observed standard deviation of the difference into Equation #3 of Appendix 7 or STPLAN. You can then modify your initial estimate of sample size accordingly.

6. Calculating the sample size necessary to detect changes between two time periods in a proportion when using permanent sampling units

Appendix 7 gives no formulas to calculate the sample size necessary to detect changes between two time periods in a proportion when using permanent sampling units. Appendix 16 does, however, describe how to use the program STPLAN to calculate sample size when you have 2 years of data from these types of permanent sampling units. Appendix 18 describes a method that you can use to derive an estimate of the sampling unit transitions that might be expected based on a single year's data and an ecological model of the plant species you are monitoring. You are strongly encouraged to read Appendix 18 if you are considering using permanent frequency quadrats.

H. Computer Programs for Calculating Sample Size

Believe it or not, most of the general statistical programs do not include routines for calculating sample size, despite their expense. Thomas and Krebs (1997) reviewed 29 computer programs for calculating sample size. They also maintain a World Wide Web site with information on how to order these programs. Refer to Chapter 11, Section L, for the address.

For beginner to intermediate level use, Thomas and Krebs recommend one of the following three commercial programs: PASS, NQUERY ADVISOR, or STAT POWER. The first one on this list, PASS, was the one most preferred by a graduate student class. Refer to their website for information on the cost of these programs and how to order them. Thomas and Krebs also give relatively high marks to the program GPOWER, primarily because it is free.

The documentation for GPOWER is extremely limited, and the user must have familiarity with Cohen's (1988) treatment of power analysis (Thomas and Krebs 1997). For these reasons we do not recommend the program for the sample size determination and power analysis needed for the types of monitoring treated in this technical reference. Instead, we suggest you consider the following two programs (unless you have the money to purchase the commercial program PASS): STPLAN and PC SIZE: CONSULTANT. STPLAN, currently in version 4.1, is free. PC SIZE: CONSULTANT costs $15 as shareware. Both can be downloaded from the World Wide Web. See Chapter 11, Section L, for the addresses.

STPLAN will calculate sample sizes needed for all the types of significance testing discussed in this chapter, but will not calculate those required for estimating a single population mean, total, or proportion. It will also calculate sample sizes for permanent frequency quadrat designs. PC SIZE: CONSULTANT will calculate sample sizes for all of the significance tests discussed in this chapter, as well as sample sizes required to estimate a single population mean or total. It will not, however, calculate sample size for estimating a single population proportion. Both programs are DOS-based and not, therefore, particularly "user friendly." They are not difficult to learn, however, and documentation files are included when you download the programs. Appendix 16 gives instructions on the use of these two programs for calculating sample sizes.

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