# Chapter 3

# BASIC SURVEY DESIGN

The proper design of aerial line transect surveys is as important for obtaining reliable results as correctly using observation procedures during surveys. Wyoming's application of line transects to aerial pronghorn surveys is based upon statistical sampling principles and not total counts of a population. The major advantages of sample-based estimates over attempted total counts are cost-efficiency and estimates of precision which help to assess the quality of the density estimates (Guenzel 1994). How accurate estimates from line transect surveys are depend upon how thoroughly the survey is designed and how well it is performed. It is extremely critical that persons responsible for the design also be familiar with the assumptions and procedures for conducting and analyzing surveys.

This chapter emphasizes the design of basic surveys for management purposes. It should be viewed as a first step and not an end. This chapter only introduces statistical sampling, survey design principles, and more advanced options like stratification. Users should consider this as a supplement to Buckland et al. (1993) and refer specifically to Chapters 1, 2 and 7 of that book. Persons having research applications or desiring more precise estimates should consult more advanced references for designing surveys. Suggestions for the design of aerial line transect surveys can be found in Buckland et al. (1993), Johnson and Lindzey (1990), Quang and Becker (1996) and Guenzel (1986). Buckland (1994), Conroy and Smith (1994) and Samuel and Garton (1994) provide some general advice on designing large scale surveys.

I strongly encourage those interested in designing aerial line transect surveys to seek advice from experienced biologists and statisticians who are familiar with line transect sampling, and particularly with the Wyoming Technique. It is important to plan surveys to achieve a high degree of quality control. The survey should be designed to maximize the likelihood of meeting assumptions for the technique. Do not plan to collect other data like pronghorn classifications during these surveys. Users should have realistic expectations of the reliability of estimates. Part of the proper design of surveys is determining the minimum level of precision acceptable for the survey's objectives. Logistical constraints like cost, aircraft availability, and manpower also need to be factored into the survey design. Remember that the Wyoming Technique may not work in some circumstances.

### *Review of Assumptions*

The basic assumptions required for line transect sampling and their adaptation to the Wyoming Technique were discussed in detail in the Introduction of this manual. Surveys should be designed to satisfy the three basic assumptions. These are briefly stated again:

1. All pronghorn on the line are seen,
2. Pronghorn do not move before being detected, and
3. Pronghorn can be placed in the correct distance band.

The survey must be designed so that placement of transects is random with respect to the distribution of pronghorn.

## BASIC SAMPLING CONCEPTS

The valid estimation of pronghorn abundance using aerial line transect surveys depends upon the proper application of statistical principles for sampling and inference. Detailed explanation of these concepts is beyond the scope of this manual. However, certain key concepts are emphasized here. I assume that persons designing surveys have some proficiency in statistics. An introduction to sampling principles can be found in most introductory statistics texts. Other helpful information occurs in various biological and sampling references (e.g., Cochran 1977, Caughley 1977b, Thompson 1992, Seber 1982, Zar 1984, Krebs 1989, Ratti and Garton 1994, Bart and Notz 1994, Lancia et al. 1994). Some general discussion on sampling in aerial surveys can be found in Swank et al. (1969), Caughley (1977a), Norton-Griffiths (1978), Australian National Parks and Wildlife Service (1979), Gasaway et al. (1986), Krebs (1989) and Wilson et. al. (1996).

### Sampling

Aerial line transect surveys are based on sampling a representative portion of the area of interest rather than attempting to survey the entire area. Some basic sampling concepts and statistical terms need to be reviewed here. These terms are discussed in the design of surveys and in the interpretation of survey results, such as output from DISTANCE:

- **accuracy:** The accuracy of the survey relates to how close the estimate is to the true value for the population (see Fig. 3.1). An estimate is customarily considered accurate if it is both unbiased and precise (see White et al. 1982, Ratti and Garton 1994).
- **precision:** Precision is how close repeated measurements are to each other (see Fig. 3.1).
- **cluster:** One or more animals in an association distinct from other such groups.
- **bias:** Bias is how far the average value of estimates is from the true value (see Fig. 3.1). Bias often results from systematic errors. In line transect sampling, cluster size bias must be considered (it is easier to detect larger clusters than individual animals, particularly when they are farther from the transect line).
- **point estimate:** The estimated value of a parameter. Results of the survey will provide point estimates for the population total and density for both individuals and clusters.
- **sampling object :** The sampling object is a cluster of pronghorn and not individual pronghorn (although a cluster can be made up of one animal). The surveys are planned for a target number of clusters of an expected average size because sightings are not independent.
- **number of observations, $n$:** The number of clusters observed is the "sample size" in this application rather than the number of individual pronghorn because sightings of individuals are not independent.
- **sample unit = line, $l_i$:** The sample unit is the individual transect line and not clusters of pronghorn (Buckland et al. 1993).
- **standard error ($se$):** The standard error is a measure of precision for a parameter estimate such as a mean.

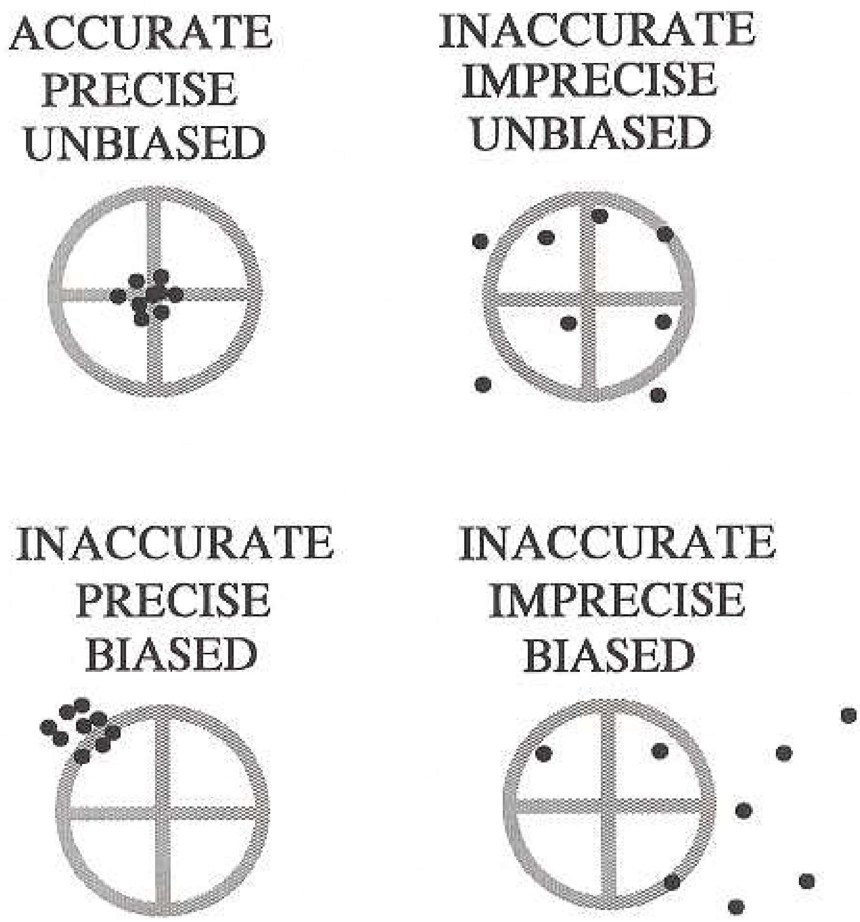


**Figure 3.1. Comparison of accuracy, precision and bias (*after* White et al. 1982).**

- **$\alpha$ level:** This is the level of significance that the true population value is contained within the confidence interval.
- **confidence intervals:** Confidence intervals are useful for quantifying the uncertainty associated with particular point estimates. These give the range in which the true value is expected to occur for a given probability level.
- **coefficient of variation (*cv*):** Coefficients of variation are relative measures of variability useful in evaluating the precision of estimates. These are calculated as the standard error divided by the point estimate for the parameter. These are often multiplied by 100 and expressed as percentages. These can be interpreted as standardized measures of precision for comparative purposes.
- **sensitivity:** One consideration in the design of surveys is how much of a difference can be reliably detected for the survey design and sample size. This involves the probability of making a Type I ($\alpha$; rejecting the null hypothesis when it is true) or a Type II ($\beta$; accepting the null hypothesis when it is false) error. This relates to the concept of statistical power (i.e., $1-\beta$; see Zar 1984, Lipsey 1990). Many aerial line transect surveys will not be able to detect subtle population changes unless they are designed specifically to do so (Guenzel 1994).
- **simple random sampling:** A random sample is one in which every member of the population has an equal and independent chance of being included in the sample. Line transect sampling does not require that animals are distributed randomly. For aerial surveys, transect lines could be selected at random but this is usually less efficient than using a systematic sample with a random start.
- **systematic sampling:** A systematic sample is one in which the sample is allocated in some uniform manner, such as spacing transects a set distance apart. For aerial surveys, systematic samples using a random start usually provide acceptable results and can often be superior to random sampling.
- **stratified sampling:** A stratified sample is one where the study area is divided into nonoverlapping subpopulations or units (i.e., strata) and each stratum is sampled separately. In aerial line transect surveys, strata are often defined by density classes. The allocation of sampling effort usually varies among strata with more effort being placed in higher density strata. Reasons for stratifying include the need for separate estimates and confidence intervals for each subpopulation, differing sampling problems among strata, improving precision of estimates, and administrative convenience (Krebs 1989). The sampling scheme within strata can be systematic or random.

## DESIGNING THE BASIC SURVEY

Persons designing and using results from aerial line transect surveys should have a clear understanding of the advantages and limitations of using this technique. Users should maintain objectivity and critically evaluate all phases of these surveys. Although the technique offers many advantages over traditional trend counts, the technique is quality control intensive (Guenzel 1994). A great deal of care should be exercised in designing line transect surveys. Make use of whatever prior information is available in designing these surveys.

The following sections discuss how to set-up basic surveys including estimating the length of transects needed to obtain the desired sample and laying out the transects. This discussion covers introductory concepts and simple designs that are suitable for initial surveys. Survey designs should be refined as specific knowledge on individual populations is acquired. Users should consult Buckland et al. (1993) for more advanced designs.

### What is a Basic Survey

The basic design for aerial line transect surveys using the Wyoming Technique is to systematically space transects across the study area using a single random start (i.e., randomly selecting an initial heading from which transects will be spaced). Most line transect surveys use a systematic layout of parallel transects because of practicality and ease of design. Transect orientation must be carefully considered so that survey lines do not parallel some inherent pattern which makes the sample unrepresentative of the population (Buckland et al. 1993). Where possible, systematically-spaced transects should be oriented across gradients in pronghorn density to homogenize the variability among transects (Johnson and Lindzey 1990).

### Survey Objectives

In designing aerial line transect surveys, have a clear idea of the objectives of the survey and how the data will be used. Keep the design simple. Do not try to do too much, such as trying to collect other data simultaneously. Too often, persons conduct surveys and then use the data beyond what is appropriate. The following questions are intended to help users clarify the purpose of the survey:

1. **What do we want to know?** The basic intent of these line transect surveys is to estimate the abundance of pronghorn in a particular region at a specific time. These surveys provide estimates of the population total and density along with measures to judge the accuracy and uncertainty associated with the estimates. Secondarily, the technique can provide information on the relative distribution of pronghorn clusters. For some questions, line transect surveys may not be appropriate tools. Usually, we want to monitor the size of specific pronghorn populations to see if management prescriptions are directing herds toward specific targets for population size. Line transect estimates can also be used to validate and align herd simulations (Guenzel 1994).

2. **What is the target population?** The population to be surveyed should be clearly defined (Buckland et al. 1993). For most Wyoming surveys, this will be a specific herd identified for management purposes.

3. **What is the geographic area to which the estimate applies?** The geographic area to which the line transect estimate will apply must be clearly delimited (Buckland et al. 1993). Normally, this will be individual pronghorn herd units identified by the Wyoming Game and Fish Department. You will need accurate estimates of the area in which populations will be surveyed because population totals are derived from the product of density and area.

4. **How reliable do we want the estimate?** The survey needs to be designed to adequately address the objective for the survey. You must decide how much of a change you hope to be able to detect and how tight you want confidence intervals to be. Conversely, budgetary and other constraints may impose limitations on the sensitivity of the survey design. These limitations should be recognized in advance.

5. **How frequently to survey herds?** If the intent of the surveys is to reliably detect changes over time, you need to consider how long to go between surveys and how sensitive the surveys must be. Often the trade-off becomes one of sampling more intensively but less frequently versus sampling less intensively but more often.

6. **What are the limitations of the survey?** More times than not, budgets, manpower, logistics or other factors do not permit surveys to be conducted at the level of precision we would like. Sometimes, observers do not conduct the survey properly or equipment failures result in incomplete data recording. It is important to recognize the limitations of surveys and whether or not data are adequate for the objectives of the survey (Otis 1994).

7. **When to survey?** The timing of the survey is important since estimates are time-specific. The survey objective may dictate when to conduct the survey. Although population objectives for pronghorn in Wyoming are set for post-hunting season (wintering) numbers, most line transect surveys are conducted at the end-of-the biological year (just prior to fawning). Timing can also have a bearing on the appropriateness of estimates. Ideally, populations should be closed. Unless you are specifically interested in changes in abundance due to migrations, surveys should be conducted after animals have reached their summer home ranges.

   - **Time of year:** Best results are usually obtained when surveys are conducted near fawning (around June 1). Cluster sizes are smallest then and pronghorn (at least in Wyoming) tend to be maximally dispersed. Under those circumstances, it is easier to obtain adequate samples. In winter, pronghorn tend to occur in larger but fewer groups. At that time of year, accurate estimation of cluster size becomes problematic and usually a considerable amount of sampling effort is required. Suppose you have a population of 2,000 pronghorn in a 600 $mi^2$ area. If the cluster size averages 2, there are potentially 1,000 clusters to encounter during a survey. Even if you could only detect half, there would still be 500 clusters that could be sampled. During winter, cluster sizes could average 50 animals or more. Under that scenario, only 40 clusters could potentially be encountered during the survey. Even if the animals were all concentrated in a much smaller area (e.g., 200 $mi^2$ ) during winter, it may take a prohibitive sampling effort to obtain an adequate sample size.

     A number of herds in Wyoming are not geographically closed. About a third of the herds in the state have interchange with populations in adjoining states. Ideally, <u>the</u> population should be surveyed simultaneously in both states. Often, that is not possible. In those instances, the survey should be conducted when pronghorn have arrived on their summer ranges and not during periods of migration. Also, periods of unusual weather (e.g., late spring snows, extremely dry periods) may temporarily influence pronghorn distributions. Try to postpone surveys until more typical distributions occur.

Adequate samples from line transect surveys can be obtained in most Wyoming herds in one to three days. Try not to drag out surveys over extended periods to avoid confounding from changes in mean cluster size, pronghorn distributions, and total numbers. Around fawning, some but not all fawns may be seen. Exclude fawns in those surveys. You can include fawns when the chance of seeing them is as good as seeing adults. This would be after late July when fawns have grown, are more active and are conspicuous. Make sure you compare estimates from different years for similar times of the biological year.

- **Time of day:** The effect of time of day on observability of pronghorn is more subtle than seasonal timing. However, you are better off to survey during early morning and late afternoon when pronghorn are more active and more dispersed. Pronghorn tend to group up and bed down during mid-day. Surveying at optimal times of the day will increase the sample size obtained per unit of sampling effort.

Once you have clearly identified the survey objectives and desired level of precision, you can proceed to estimate the sample size and allocate transects.

## DETERMINING THE DESIRED "SAMPLE SIZE"

Several factors must be considered in determining the desired sample size for the survey. As discussed later, sample size in line transect sampling is usually expressed in terms of total transect length to be sampled. The transect length should be adequate to encounter a sufficient number of clusters for the desired level of precision.

Some factors that are considered in designing surveys include:

Budget - The available budget may limit the total transect length that can be sampled. In those situations, it may be worthwhile to estimate the level of precision that will result from the sample to be obtained within the budget and see if that meets the objectives for the survey.

Survey Objective - How good of an estimate is needed to fulfill the objectives of the survey? Should resources to conduct the survey be allocated to other areas if the results of the planned survey would be inadequate for the intended purpose?

Manpower - In some instances, only one observer may be available because of aircraft or personnel limitations. This must be considered in the design of the survey to assure that the sampling effort is adequate to obtain the desired sample.

Population Size and Density - Adequate sample sizes are easier to obtain for a given amount of relative effort in larger populations and/or herds with higher densities of clusters. Often the same amount of survey effort may be needed for a smaller population as for a larger, more expansive herd.

Desired Precision - The desired level of precision for the population estimate is a major determinant of sample size adequacy. Usually, a preliminary survey must be performed to estimate the sample size required for a specified level of precision.
Expected Encounter Rate - Larger samples are needed where the encounter rates are lower or more variable in order to meet sample size requirements for a given level of precision.
Expected Cluster Size - For a given population size, the smaller the expected cluster size, the more clusters there are to potentially be encountered. Although smaller clusters are harder to see, larger sample sizes are typically obtained when surveying during the period that pronghorn are more widely and evenly dispersed into smaller clusters (i.e., near fawning). Variation in cluster sizes also contribute to the variation in density estimates.
Area to be Surveyed - For a given population size, it usually requires surveying more transect length in a herd that occupies a large geographic area than a herd living in a smaller area. This relates to encounter rate considerations discussed above. In some cases, stratification or excluding very low density areas (essentially unoccupied habitats) from the survey may help.
Population Distribution - In populations where the distribution of clusters is highly clumped, more sampling may be required to estimate the population within the prescribed level of precision. This also relates to encounter rate considerations.
Number of Transects - The number of individual transect lines, or segments will have an influence on the precision of the estimate primarily as it reflects variation in encounter rates among lines.

Given some knowledge about the population to be surveyed, formalized statistical procedures can be used to estimate the desired sample size for a desired level of precision (see Buckland et al. 1993:303-306). Using those procedures requires conducting an initial survey or having comparable data from a prior survey. One approach is shown later in this chapter.

Some *ad hoc* sample size recommendations may be useful as a first cut for designing many basic surveys for management purposes. Often, circumstances (e.g., budgets, aircraft availability, etc.) do not allow for conducting a detailed preliminary survey on which to refine the design and complete a more intensive survey. In some cases, results from previous surveys may not be suitable for planning other surveys because the population size has drastically changed or other circumstances are not comparable to the prior survey (time-of-year, seasonal weather patterns, etc.). The appropriateness of using these *ad hoc* procedures depends upon the survey objective and the desired level of precision. These should be considered as minimum sample size guidelines. It is up to the user to be sure the survey is designed and conducted adequately to meet the survey objectives. The following procedures are useful for designing initial, basic surveys.

One of the biggest areas of misunderstanding in aerial line transect sampling is what constitutes the minimum acceptable sample size (number of clusters). The minimum sample of 40 objects (clusters) discussed in Burnham et al. (1980) has been misconstrued by some to be an adequate sample. Gates et al. (1983) suggested that 100 objects was more appropriate. Although Buckland et al. (1993:302) suggest 60 to 80 objects as a practical minimum, they note that larger samples are needed for a given level of precision for clustered populations such as encountered in aerial pronghorn surveys.

One of the major areas of misunderstanding in applying the Wyoming Technique has been how many clusters are needed to obtain an adequate sample. The number of clusters observed during the survey is important for two main reasons: (1) to estimate the detection curve adequately, and (2) because encounter rates typically account for a major proportion of the variance in density estimates. With the limited number of distance intervals imposed by the Wyoming Technique, it is important that the histogram of observed distances reflect the true detection function. With small sample sizes (e.g., n=20), the assignment of one cluster in a particular distance band could account for a major change in the shape of the histogram (with 20 observations, 1 cluster would account for 5% of the observations). Distances are subject to some random and systematic errors.

With the exception of herds occupying relatively small areas or low density populations, minimum sample sizes for estimating densities commonly seen in Wyoming pronghorn herds should be at least 200 clusters and often more, depending upon the desired level of precision and required line length.

The total transect length needed to be sampled to obtain a desired level of precision is largely a function of cluster density (clusters/mi $^2$) and not area. For example, the total line length needed to encounter a sample of 200 clusters is the same for a herd occupying 500 mi $^2$ as for one occupying 2,000 mi $^2$ if the cluster density is the same. There will be more total clusters in the larger area, however. Transects would likely be spaced farther apart in the larger sized herd. Care must be taken to assure that spacing lines farther apart does not increase variability of the estimated population size.

## Determining the Total Transect Length

The following discussion describes how to estimate the total transect length needed to encounter the desired number of clusters as selected using the above guidelines. One statistical procedure for estimating total transect length based on a preliminary survey is presented later in this chapter.

Once the target number of clusters has been selected, the estimated total transect length to obtain this sample can be estimated using the following steps:

**Step 1. Obtain Planning Data:** Prior to calculating the transect length needed, $L$, you should have the following data available:

(a.) **Target Number of Clusters to Encounter, $n_s$ :** This is the total number of clusters you hope to encounter during the survey.

(b.) **Area of Survey, $A$:** This is commonly the estimated area (usually in square miles) for the geographic region you intend to apply the estimate to (e.g., herd unit). Frequently, this will be an estimate of the total occupied habitat (TOH). Estimates for TOH are available for many Wyoming herds. Alternatively, area can be estimated from a GIS, a herd unit database, by planimetering the area on a map, using a dot grid, or counting square miles from a land status map. There are some special cases that can arise. You need to decide how to handle these situations in advance:

- Unoccupied habitats: For many herd units, unoccupied habitats are relatively small and/or dispersed throughout the area. These are usually not worth excluding from the survey (e.g., some small mountains, isolated groves of trees, rock outcrops, reservoirs.). In these situations, go ahead and survey the entire herd unit and use the total area in the analysis. Often, large unoccupied habitats can be excluded. This requires estimating the actual area of the survey (or excluding the area of these unoccupied regions). GIS, planimeters and other methods can be used to adjust the area estimates. In some cases, pronghorn occur in very low densities (areas essentially devoid of pronghorn) or do not occupy certain large, discrete regions. Where it is feasible to exclude those areas from the survey, use an estimate of the area of occupied habitat. This requires that the lines be terminated, or interrupted over the unoccupied areas during the survey (observers will have to advise the pilot of these). These may be appropriate to use here.

- Areas which can't be surveyed: Occasionally, some occupied areas cannot be surveyed from the air. In most cases, these circumstances occur in fairly small areas and will have a negligible effect on the estimated population size given the variability of most estimates. This problem can result where there is restricted air space (such as military bases and training areas, some national parks, or near airports or cities) or where it may be too hazardous to survey (e.g., terrain is too confining, prevailing downdrafts in the foothills of mountainous areas, large radio or powerline towers, etc.). In some instances, you can decide if the densities in those areas are comparable to adjacent, accessible habitats or not. If they are (or you are willing to assume so), then you need not make any adjustments. The population size will be determined from the average density for the herd. If you suspect pronghorn densities in those large areas are substantially different, you will have to make some assumptions in order to adjust your estimates. Calculate the area that can't be surveyed and exclude that from your line transect estimate. Obtain an estimate of the numbers in the restricted area by a ground survey or some other technique and add the total to the line transect estimate. Be sure to state how you handle this problem in your report.

(c.) **Initial population estimate, *N*:** You need to supply a population estimate for the herd at the time of the survey in order to estimate the length of transect needed to encounter the desired number of pronghorn clusters. For most Wyoming pronghorn herds, these estimates can be obtained from tabular output from an acceptable POP-II simulation (Bartholow 1990). For most Wyoming surveys occurring around fawning (e.g., within a month of June 1), use the simulated population size at the end of that biological year. If you plan to survey at other times, use the appropriate estimate for that season (e.g., Late July-August = Preseason, Late October (some areas) = Postseason, etc.). When you don't have an acceptable simulation, use your best judgment. A population estimate can be derived from a previous total or trend count divided by a sightability factor (e.g., divide the estimate by 0.67 if you believe you counted two-thirds of the population). It is probably best to err conservatively (i.e., smaller population estimate) in these circumstances. Most cases where you don't have acceptable simulation estimates are for small populations that aren't as amenable to line transect sampling anyway. Some potential strategies for these situations are discussed later.

**(d.)** **Expected cluster size, $\bar{s}$:** Using these procedures, you must select an expected cluster size for the survey in order to estimate the transect length. It is probably best to assume a slightly larger cluster size than you really expect. That should give a more conservative estimate. As shown later, cluster size can be quite variable from year to year for the same time of year. Estimates of cluster size can be obtained using data from previous line transect surveys, ongoing line transect results from neighboring herds, ground reconnaissance, or by assumption. In Wyoming, pronghorn typically occur in clusters of 1.5-2.5 around fawning, with larger sizes preceding and following that period. Assuming an average cluster size of 3.0 may give a conservative estimate of total transect length for late May-mid-June surveys in many circumstances.

**(e.)** **Expected effective strip width, *w*:** The effective strip width is the total perpendicular distance from both sides of the transect line at which the total number of clusters detected equals the actual number out to that distance. An estimate of the effective strip width is needed for estimating the total transect length since this is the average "strip width" in which you detect the requisite number of clusters. For most aerial line transect surveys of pronghorn using the Wyoming Technique, the effective strip width tends to run between 200 and 280 meters (it will be converted to miles for our use here). We effectively account for 50-70% of the pronghorn that are within the 400 meters-wide strip (counting both sides) marked on the plane. For planning purposes, using 200 meters tends to be a bit conservative for surveys around fawning (e.g., the end-of-the-biological year), based on results of Wyoming surveys. If you use only one observer (looking out one side of the plane at a time), be sure to halve the effective strip width. That means you would have to fly twice as many lines to get the required number of clusters using one observer.

**Step 2. Estimate Cluster Density, $D_s$:** Using the data above, divide the population estimate ($N$) for the time of the survey by the expected cluster size ($\bar{s}$) Then divide that quantity by the area ($A$)to which the estimate will apply. Equation 3.1 describes this relationship:

$$D_s = (N/\bar{s})/A \qquad \text{(Eq. 3.1)}$$

**Step 3. Estimate Area to be Surveyed, *a*:** To estimate the area that should be sampled to encounter the desired number of clusters, $n_s$, divide the desired number of clusters by the density of clusters as shown in Equation 3.2:

$$a = n_s / D_s \qquad \text{(Eq. 3.2)}$$

**Step 4. Estimate the Total Transect Length to be Surveyed, *L*:** Divide the area ($a$) to be surveyed from Equation 3.2 by the effective strip width. Be sure that you convert the effective strip width ($w$) to the same units you want line length determined. Equation 3.3 shows this calculation:

$$L \quad = \quad a/w \qquad \text{(Eq. 3.3)}$$

The above calculations should be used as *general guidance* for estimating the total transect length needed to be surveyed in order to encounter the prescribed number of clusters. This is just one consideration in designing surveys. Users should recalculate these periodically during the survey to determine if adjustments to the sampling intensity are warranted.

For certain sample sizes under special conditions (e.g., low density herds, large expected cluster sizes, etc.), the expected line length may approach or exceed what would appear to be a census of the entire area. Under those scenarios, users are strongly urged to revisit their assumptions about the populations and how reliable an estimate is needed. Some strategies for surveying low density herds are discussed later in this chapter.

Iron Mountain Pronghorn Herd - Example

The following example will help demonstrate the above calculations. Suppose you wanted to survey the Iron Mountain Herd in southeastern Wyoming at the end-of-the-biological year (e.g., June 1). The POP-II model simulates an end-of year population ($N$) of 12,500 pronghorn for the time of the survey. The survey will sample from the entire 2,280 mi$^2$ ($A$) that the herd unit encompasses (e.g., no area adjustments). Based on precision levels from previous surveys, you hope to get a sample of 300 clusters. For this time of year, you choose an expected cluster size ($s$) of 3 to err conservatively. You use an effective strip width ($w$) of 200 m as a conservative estimate, based on results from previous surveys at this time of year. From Equation 3.1, we estimate the density of clusters:

$$D_s \quad = \quad \frac{12{,}500 \text{ animals/3 animals per cluster}}{2{,}280 \text{ mi}^2} \quad = \quad 1.83 \text{ clusters/mi}^2$$

Using Equation 3.2, we derive the area we need to survey:

$$a \quad = \quad \frac{300 \text{ clusters}}{1.83 \text{ clusters/mi}^2} \quad = \quad 163.9 \text{ mi}^2$$

To estimate the total line length needed, we first convert our effective strip width of 200 m to miles:

$$w = \frac{200 \text{ m}}{1{,}609 \text{ m/mile}} = 0.1243 \text{ mile}$$

Now, we can substitute into Equation 3.3 to get the total miles of transect we need to survey:

$$L = \frac{169.3 \text{ mi}^2}{0.1243 \text{ miles}} = 1{,}362 \text{ miles}$$

These equations are to be used as a guide. If you find that cluster sizes are smaller than expected, you can recalculate the estimated line length. In this example, $L$ reduces to 880.5 miles if $s$ is 2 because the density of clusters is higher.

**Program LTSAMPLE:** A computer program, LTSAMPLE, was written by the author to perform the above calculations as used in the Wyoming Technique. Users enter a title, a population estimate, the area to be surveyed in square miles, and the desired number of clusters. The program generates a table of line lengths (in miles) for expected cluster sizes from 1 to 20 and effective strip widths of 25, 50, 100, 200 and 400 meters. The output table can be used to adjust the sampling intensity when actual field observations differ from the assumed values. Users can also interpolate from the table.

The calculations implemented in LTSAMPLE were used to generate Table 3.1. The table lists the estimated total line lengths needed to encounter the expected number of clusters over a range of cluster densities assuming an effective strip width of 200 m (counting both sides of the plane). This *ad hoc* table should only be used as a general example and starting point for planning basic management surveys where planning data are limited. For some large area herds, sampling additional miles of transect may be required to obtain reasonably precise estimates.

Depending upon the objectives, larger sample sizes may be needed. In some instances, selecting a smaller size may also be adequate. The spatial distribution of clusters during the survey will have some bearing on the adequacy of a particular sample size. For small to medium, low density herds, one of the alternatives described later in this chapter may help reduce the amount of sampling needed. Where there are questions about whether a herd has increased, planning a survey for the larger estimate by spacing lines farther apart (or flying every other line) may be appropriate. If the herd has increased, the sample size may still be adequate and you wouldn't have spent more money and effort than needed to meet the objectives of the survey. If the population is lower than expected, you can go back and fly additional transects to increase the sample size.

**Table 3.1. Estimated total transect lengths (miles) needed to survey to obtain the expected number of clusters for specified cluster densities, assuming an effective strip width of 200 m (0.1243 miles). This table should only be used an example and initial guide.**

| | CLUSTER DENSITY (clusters/square mile) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Desired Number of Clusters to Encounter** | **0.5** | **1.0** | **1.5** | **2.0** | **2.5** | **3.0** | **3.5** | **4.0** | **4.5** | **5.0** |
| **50** | 805 | 402 | 268 | 201 | 161 | 134 | 115 | 101 | 89 | 80 |
| **100** | 1609 | 805 | 536 | 402 | 322 | 268 | 230 | 201 | 179 | 161 |
| **200** | 3218 | 1609 | 1973 | 805 | 644 | 536 | 460 | 402 | 358 | 322 |
| **300** | 4827 | 2414 | 1609 | 1207 | 965 | 805 | 690 | 603 | 536 | 483 |
| **400** | 6436 | 3218 | 2145 | 1609 | 1287 | 1073 | 919 | 805 | 715 | 644 |
| **500** | 8045 | 4923 | 2682 | 2011 | 1609 | 1341 | 1149 | 1006 | 894 | 805 |

**Using Data From a Preliminary Survey to Estimate Transect Length:** More rigorous procedures exist to estimate the desired sample size for line transects (e.g., Buckland et al. 1993). These require some prior knowledge about the population to be surveyed. Because the number of objects to be detected (pronghorn clusters in this application) is a random variable, these sample size procedures typically estimate the line length needed to be surveyed (Buckland et al. 1993). One can estimate the number of objects *expected* to be encountered when surveying the prescribed total length of transects, however, from the length of transects required.

The following equations are used to approximate the length of transect line, $L$, to be surveyed to achieve a desired level of precision (expressed as a target coefficient of variation, $cv_t$ ) based upon results of a preliminary survey. Persons interested in using this approach should review Section 7.2.2 in Buckland et al. (1993:303-306) before proceeding. There are several possibilities for obtaining preliminary estimates for use in this equation: (1) use results of an initial, smaller scale survey (e.g., fly a small survey to estimate encounter rates); (2) use partial results of an ongoing survey; (3) use results from a previous, comparable survey; or (4) use "expected" values for the anticipated survey conditions and population. Each of these approaches requires making certain assumptions. In all cases, the values used should be representative for the population at the time you conduct the survey. Using results from a survey conducted two years ago may be appropriate if the population density is assumed to be about the same level as the earlier survey and expected cluster sizes will be about the same. However, it may often be inappropriate to use the results of the previous survey because the population has changed significantly from the previous estimate, cluster sizes are expected to be different due to the timing of this survey, or many other factors.

The following equations have been adapted from the presentation in Buckland et al. (1993) so users can more easily incorporate results from an initial survey that was analyzed using

DISTANCE. These equations are intended for persons using a survey design like the Wyoming Technique.

$$L = \frac{L_0 * b}{n_0 * cv_t^2} \qquad \text{(Eq. 3.4)}$$

and,

$$b = n_0 * [\{cv(D_S)\}^2 + \{se(\bar{s}_0) / \bar{s}_0\}^2] \qquad \text{(Eq. 3.5)}$$

| | | | |
|---|---|---|---|
| *where:* | $L$ | = | the total length of line to be surveyed for the target level of precision |
| | $L_0$ | = | total line length surveyed from an initial survey |
| | $b$ | = | dispersion parameter |
| | $n_0$ | = | number of clusters observed on the initial survey |
| | $\bar{s}_0$ | = | bias-corrected mean cluster size from the initial survey *(from the DISTANCE output)* |
| | $\hat{se}(\bar{s}_0)$ | = | standard error for the bias-corrected cluster sizes *(from the DISTANCE output)* |
| | $cv(D_S)$ | = | coefficient of variation for the estimated density of clusters *(from the DISTANCE output)* |
| | $cv_t$ | = | desired (target) coefficient of variation for estimate of the population density (e.g., 0.1, 0.15, etc.). |

Although Buckland et al. (1993:304) recommend substituting the value 3.0 for $b$ in Equation 3.5, results from Wyoming aerial line transects typically run much higher. Estimated $b$s for a sample of pronghorn surveys in southern Wyoming ranged from approximately 4.0 to 10.0 with a mean of 7.3. Higher $b$s are typical of more rapidly declining detectabilities with distance. Therefore, I recommend calculating $b$ empirically where possible. For planning purposes, using a value of 7.0 or 8.0 for $b$ in Equation 3.4 seems reasonable for typical Wyoming surveys.

Using the above procedure, you can also estimate the total number of clusters that you would <u>expect</u> to encounter by flying the revised transect length, $L$, by substitution:

$$n = L * n_0 / L_0 \quad \text{(Eq. 3.6)}$$

Centennial Pronghorn Herd - Example:

A line transect survey was conducted in the Centennial Pronghorn Herd in southeastern Wyoming in June of 1993. The following results were obtained from that survey:

$L_0$ = 334.0 miles of transect

$n_0$ = 285 pronghorn clusters

$\bar{s}_0$ = 1.423 pronghorn/cluster (corrected for size bias)

$se(\bar{s}_0)$ = 0.0397 (corrected for size bias)

$cv\,(D_S)$ = 0.162

Suppose we wanted to determine how many additional miles of transect it would take to obtain an estimate with a target coefficient of variation of 15% (e.g., $cv_t$ = 0.15). We substitute the above results into our sample size equation:

$$b = 285 * [\{0.162\}^2 + \{\{0.0397 / 1.423\}^2\}] \quad \textit{(from Eq. 3.5)}$$

$$= 285 * [0.02624 + 0.000778]$$

$$= 285 * 0.02702$$

$$= 7.7$$

$$L = \frac{334 * 7.7}{285 * (0.15)^2} \quad \textit{(from Eq. 3.4)}$$

$$= \frac{334 * 7.7}{285 * 0.0225}$$

$$= \frac{2571.8}{6.413}$$

$$= 401 \text{ miles}$$

Therefore, sampling another 67 miles of transect (20% more) in this example would improve precision to the desired coefficient of variation of 15%. This illustrates the substantial amount of sampling typically required to significantly improve precision of estimates.

The number of clusters expected to be encountered if you flew a total of 401 miles instead of the 334 miles that were actually flown in this example can be estimated by substituting into Equation 3.6 above:

$$n = \frac{401 \text{ miles} * 285 \text{ clusters}}{334 \text{ miles}}$$

$$= 342 \text{ clusters}$$

Use extreme care when using results of surveys from previous years to estimate desired sample sizes in the manner described here. Table 3.2 for the Centennial Herd illustrates the variability in estimates for cluster size and encounter rates among surveys.

**Table 3.2. Comparison of line lengths, sample sizes, expected cluster sizes, precision, and encounter rates for aerial line transect surveys in the Centennial Pronghorn Herd.**

| Year | Dates | Line Length (miles), $L_i$ | Number of Clusters, $n_i$ | Expected Cluster Size, $S_i$ | Standard Error for Expected Cluster Size, se(S) | Coef. of Var. for Density of Animals, cv(D) | Coef. of Var. for Density of Clusters cv($D_S$) | Encounter Rate, n/L |
|---|---|---|---|---|---|---|---|---|
| 1992 | May 7-8 | 357.4 | 240 | 2.18 | 0.5874 | 0.169 | 0.138 | 0.672 |
| 1993 | June 20-21 | 334.0 | 285 | 1.43 | 0.0397 | 0.165 | 0.162 | 0.853 |
| 1995 | June 13 | 384.1 | 236 | 1.61 | 0.0677 | 0.175 | 0.173 | 0.614 |

**Line Length Fixed by Cost:** On occasion, budgetary limitations may determine the total length of transect to be sampled instead of statistical principles. In those instances, it is worthwhile to calculate the expected number of clusters to determine if the results will be precise enough to fulfill the objective of doing the survey. The general process is to figure out how much of the budget is available for actually flying the survey as opposed to paying other expenses such as ferry time and overnight charges. You may want to estimate conservatively since the budget may be fixed so that you can't exceed it. You can always fly additional lines if you find you are coming in under the budget. Here are the basic steps to determine how many miles of transect you can fly (some of these steps are described in more detail in the section below on Estimating Flight Time and Costs):

1. Subtract out the cost of the ferry time to and from the air charter's home airport (or wherever the plane is coming from) to the base airport near the study area that you will use. Allow for some time delays in case of headwinds or other problems.
2. Subtract the per diem charges for the number of overnight stays for the pilot.
3. Estimate the cost for flight time needed to fly from the base airport to the study area and back, and the number of times you need to do this. You may also need to allow for some practice time if flying with inexperienced observers.
4. Estimate the cost for flight time needed to go between transects. This is usually the time it takes to fly the width of the study area perpendicular to the orientation of the transect layout (more time may be needed if you split the area to fly shorter transect lines).
5. Subtract the above costs from the total available budget. This leaves the amount of money left for actually surveying transects.
6. Divide the remaining budget by the hourly cost for the survey. That gives the number of hours of flight time available for conducting the survey.
7. Multiply the hours by a conservative estimate of the survey ground speed. This gives the estimated total transect length, $L$, that you can afford to survey.

Using the procedures outlined previously, you can estimate the mean transect length and the number of transects, as well as select the systematic sample of lines.

The next question is how many pronghorn clusters you are likely to encounter during this survey. These following steps will help estimate the number of clusters:

1. Estimate the expected cluster density, $D_s$, from Equation 3.1.
2. Using an assumed effective strip width, $w$, estimate the area surveyed, $a$, when flying the total transect length, $L$ (e.g., $a = L*w$). Be sure the units are consistent (e.g., $L$ and $w$ in miles so that $a$ is in square miles).
3. The expected number of clusters to be encountered, $n_s$, is the product of the area surveyed and the expected cluster density: $n_s = D_s*w$.

Example

The following example will illustrate the above approach. Suppose you have $1,500 to conduct the survey. The flight service charges $200/hour for air charter during the survey, $150/hour for ferry time, and $60/day for per diem for the pilot. There will be 2 hours of ferry time each way to and from the flight service's home airport. That will use up about $600 of the budget. You expect the pilot to stay over one night, using an additional $60. That leaves $940 to complete the survey.

However, some time will be spent flying to and from the nearest airport to the study area, and you will also have to factor in time for going from one transect to the next. At $200/hour, you have enough money left for 4.7 hours of flight time. Suppose the study area is 30 miles wide perpendicular to the orientation of transects. You will need to go at least this distance between transects. If you break the survey into two sessions (4.7 hours is too long for one session), then you will have to factor in more time to and from the study area. It is best to use conservative estimates here. For this example, assume that you must fly an average of 25 miles each way to get to and from the study area. You plan to make two round trips plus factor in the distance for turning and going between transects (total = 130 miles). Assume that the plane will be flown about 80 mph during the survey. Of the 4.7 hours available, you will use about 1.63 to fly to and from the area and between transects. That leaves less than 3.1 hours of actual survey time. At 80 mph, you can survey about 246 miles in the 3.1 hours.

If you assume an effective strip width of 200 m (0.1243 mi), you can search the equivalent of 30.6 $mi^2$ flying 246 miles of transect. If you have calculated the expected cluster density to be 1.6 pronghorn clusters per square mile, you can expect to encounter about 49 clusters. Based upon previous experience, the estimates from such a line transect survey would be likely to be poor, granted that this example uses conservative values. You then must decide if it's important enough to allocate more budget from elsewhere to this survey. There are some strategies for piggybacking surveys with adjacent herds to help stretch budgets. Those are discussed later.

## SAMPLE ALLOCATION FOR BASIC SURVEYS

Once you have estimated the total transect length that will be needed to obtain the desired sample, the individual lines for the survey can be laid out. The basic survey design uses a systematic grid of equally-spaced transects using a random start. The transects are commonly oriented north-south along minutes of longitude, or east-west along minutes of latitude. Technically, longitudinal lines tend to converge and latitudinal lines spaced equally by minutes are not equally spaced on the ground. The effects are probably insignificant for our area. These problems are not expected to coincide with any patterns in the distribution of pronghorn in the study area.

The following principles can be used to design the transect layout for the survey. These can also be applied to the design of stratified systematic surveys by performing the following steps within each stratum instead of for the study area as a whole. Individual surveys may require some modifications to this survey design to address unique situations.

### Designing the Transect Layout

The following steps will help determine the number, spacing, and selection of individual transect lines:

Step 1. Define the boundaries for the area to be surveyed: Be sure to clearly define the boundaries of the area(s) to be surveyed. Often, major highways, rivers, terrain or habitat features (e.g., cities, forested areas, etc.) make up herd unit boundaries. In some cases, the boundary may not be observable on the ground (e.g., state lines) and a latitude or longitude will be needed to define the boundary during the survey. Be sure to exclude any areas that should not be flown.

Step 2. Determine the transect orientation: For a basic systematic survey using a random start, try to run the transects across any known gradients in density (Fig. 3.2 a and b). This will help homogenize the line-to-line variability. It is logistically easier to run the transects north-south or east-west, but parallel transects could be designed to take any heading. Many observers prefer flying north-south lines where possible because the sun angle tends to be more favorable for viewing. In some cases, running the transects across the shorter dimension may be preferable when transects would be too long running them the other direction. Alternatively, you could break long transects into two sets. Terrain, prevailing winds or other hazards may constrain the transect orientation to certain directions.

Step 3. Determine the average transect length and the basic dimensions of the survey area: Using a 1:100,000 scale or other map, approximate the average width and length (in miles) of the area to be surveyed relative to the selected transect orientation. Usually these will be along the north-south or east-west orientation. If the study area is very different from a rectangular shape, you may need to take measurements at locations other than along the edge of the study area (Fig. 3.3 a and b).

Also determine the latitudinal and longitudinal range of the study area in minutes. These can be found on 1:100,000 scale and other topographic maps. You can also use the Wyoming Department of Transportation State Aeronautics Chart or FAA sectional charts for this. These charts can also be used to determine transect spacing.

In some cases, the average transect length based on the average length or width of the study area may be too long to survey in practice. For planning purposes, you do not need to break up transects. However, observers have difficulty maintaining concentration on long transects (> 25 miles) so try to avoid designing surveys with transects longer than these. You can split the area in half and draw up two sets of shorter transects. This will double the flight distance between transects, however.

Ideally, individual transect lengths should be as consistent as possible. As a practical matter, line lengths will usually vary in length in most pronghorn herds in Wyoming.

Step 4. Determine the number of transects, *k*: Divide the total line length calculated by one of the methods in the previous section by the average transect length. Be sure the units of length are the same. This gives the approximate number of evenly-spaced transects to allocate across the area. Where transects would be too long, you may want to split the area into two sets of transects.

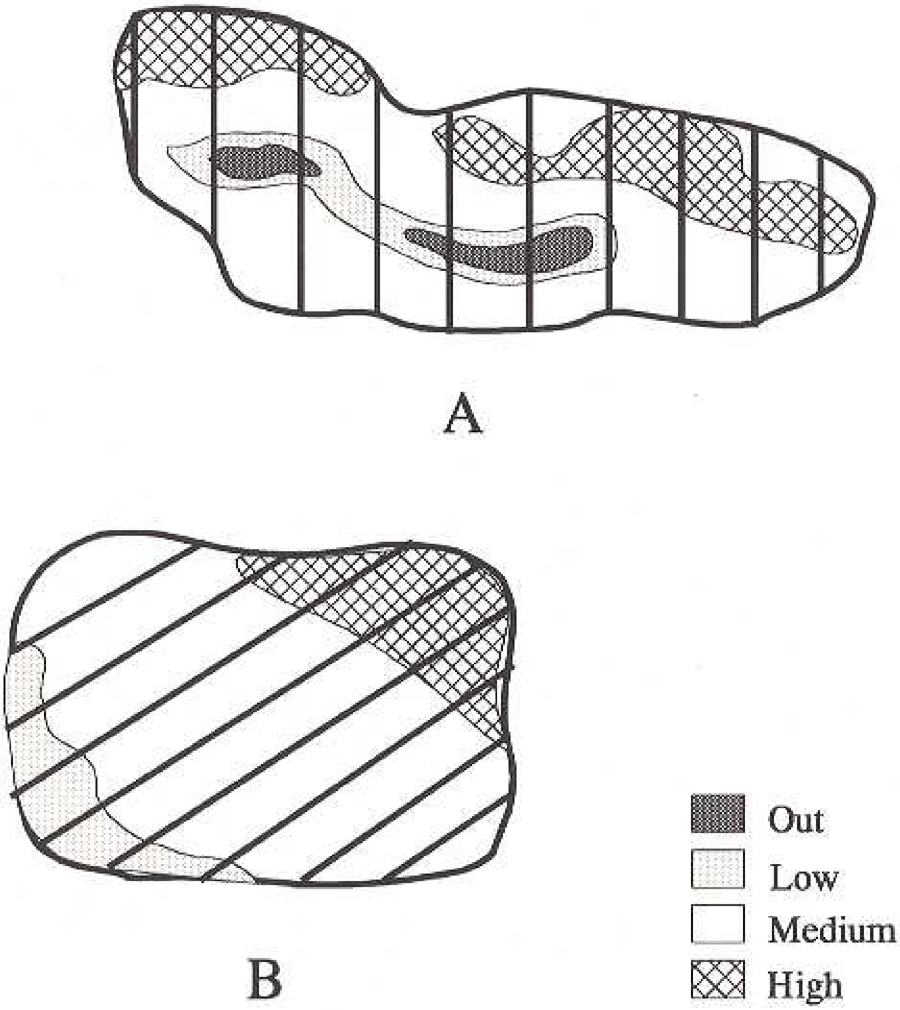


**Figure 3.2. Considerations in transect layout: (A) orienting transects across the density gradient along north-south headings, and (B) orienting transects across the density gradient for southwest-northeast headings.**

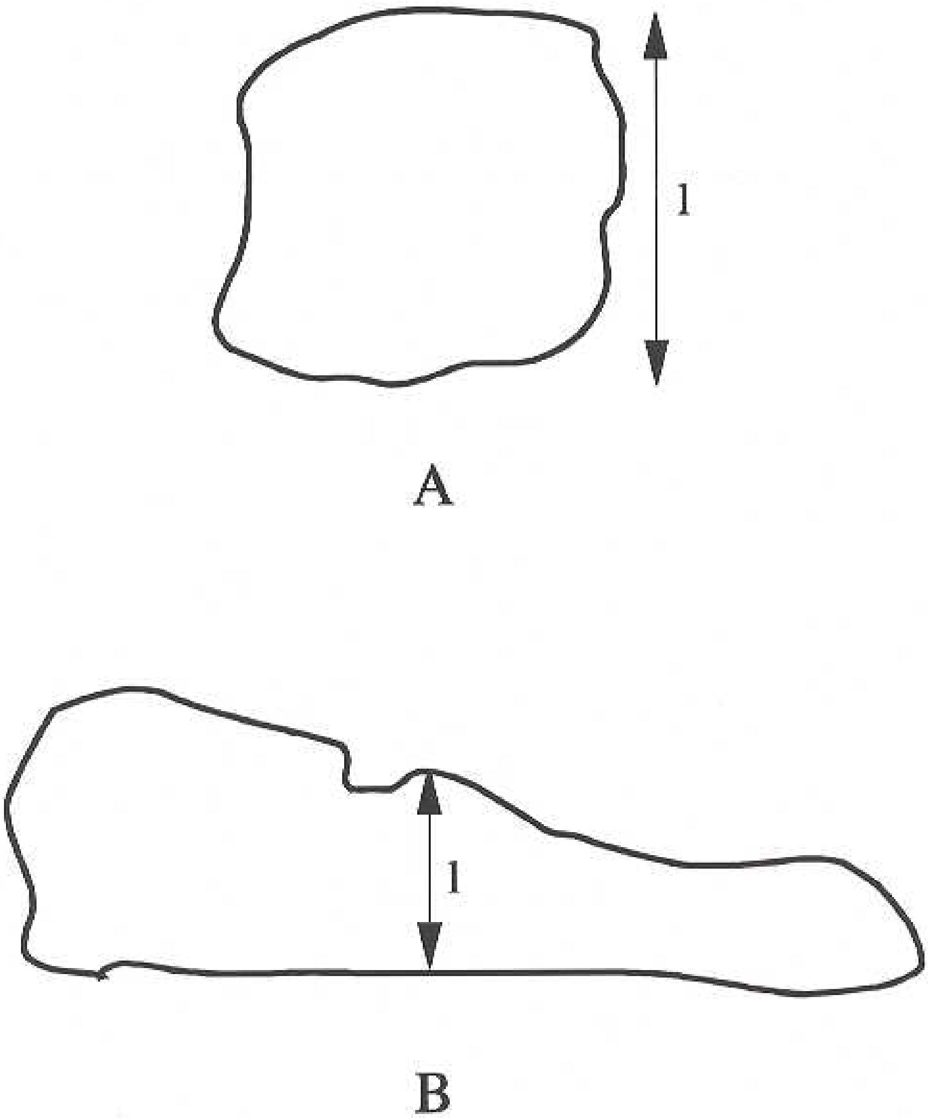


**Figure 3.3. Determining the average transect length, l, for (A) rectangular study areas, and (B) irregularly shaped study areas.**

Step 5. Determine the spacing of transects: Once you have decided upon the transect orientation and estimated the number of transects, divide the distance across the study area perpendicular to the transect orientation by the number of transects. This gives the distance to space transects apart. This will usually be along north-south or east-west orientations. In these cases, using the longitudinal or latitudinal range in minutes allows for easier selection and navigation of lines. It is easiest to round the transect spacing to the nearest minute rather than deal with decimal minutes or seconds. Note that a minute of longitude denotes different distances at different latitudes. North-south lines converge as you go away from the equator. Where possible, space transects at least two minutes apart to avoid potential for pushing animals into the next transect and counting them again.

Step 6. Select a random starting point: Randomly select an initial transect from all potential transects within the range of the study area. This can be done by multiplying the distance across the survey area by a uniform (between 0 and 1 inclusive) random number generated with a hand-held calculator. For most surveys, the list of minutes across the study area can be similarly used to select an initial transect. Alternately, you can list all potential transect headings on uniform pieces of paper and draw one from a hat. You do not need to start the survey at this transect, however.

Step 7. Allocate the transects: Once you have selected the random heading, space parallel transects out evenly across the study area using the determined spacing. In some areas, you may need to reorient transects in particular directions because of logistical constraints. When this happens, try to preserve the basic sampling intensity. You can actually start the survey at one end of the study area or the other. You don't have to start with the first randomly selected transect. In some cases, the spacing may be even minutes, in which case you could flip a coin as to starting on even or odd minutes. That makes it easier for the pilot to keep track of the next line.

Step 8. Make a list and map transects: Transect lines are assumed to be of fixed length and not random so it is important to try to fly the survey as closely to the designed layout as possible. Make a list of the transect lines and headings. A sample form is included in Appendix II. Mapping the transects is helpful for use in the plane. Be sure to review the survey layout with the pilot and observers prior to the survey. You may need to list the latitude and longitude coordinates for specific transect endpoints in some cases where a recognizable boundary does not exist on the ground. Where lines are oriented other than north-south or east-west, be sure to list the heading (e.g., 45 degrees for a northeast heading; 225 degrees for southwest, etc.).

Like all aspects of designing basic line transect surveys, these procedures are approximations for well-behaved situations. The above steps will be less suitable for more complicated designs and where logistical problems require special modifications.

Example

Suppose we want to design a survey for the Iron Mountain Pronghorn Herd and we've already estimated that we need to fly about 350 miles of transect. Terrain necessitates that we fly north-south transects. We will be covering the entire area and not just occupied habitat. The average transect length of 44 miles is too long so we break the survey into a northern block and a southern block. We split the blocks on a convenient latitude and will offset the two sets of transect lines so that we minimize duplicating observations or displacing pronghorn from one set to the other. Instead of 8 long transects (350 miles/44 miles), we will end up with about 16 shorter lines (8 lines per set).

The herd unit is about 36 minutes of longitude across. Therefore, we divide the width by 8 lines to get the transect spacing of 4.5 minutes apart. We round this down to 4 minutes since it is easier for the pilot to navigate on whole degrees, and to err conservatively in case we don't encounter clusters as often as planned.

Now we select the 8 transects for each set. For the northern block, we can multiply the width of the area (36 minutes) by a uniform random number (between 0 and 1) from a handheld calculator. In this case, the random number of 0.632 multiplied by the 36 minutes gives approximately 23 minutes. So we can start spacing transects 4 minutes apart from the 23rd minute. Suppose the east side of the area was approximated by the 105° 55" line. The west side would be bounded by the 106° 31" line. The 23rd line falls on 106° 18" so we space the transects out from that line every 4 minutes. As it turns out, we get 9 transects in the northern half:

| | | | |
|---|---|---|---|
| Line 1 | 105° 58" | Line 5 | 106° 14" |
| Line 2 | 106° 02" | Line 6 | 106° 18" |
| Line 3 | 106° 06" | Line 7 | 106° 22" |
| Line 4 | 106° 10" | Line 8 | 106° 26" |
| | | Line 9 | 106° 30" |

We can use a similar process to allocate the transects in the southern block, but we constrain the selection of lines so that we don't end up with the same headings. The transect layout might look something like Figure 3.4.

**Flying the same set of lines from survey to survey:** There is a tendency for some biologists to use the same set of transects every time they fly a survey in a particular area. The appeal of this idea is that it is easier to compare pronghorn distributions from survey to survey. However, the primary goal of the survey is to reliably estimate pronghorn abundance. Using the same lines from year to year may not yield adequate samples in some years. The population may have decreased or cluster sizes may be larger than the previous survey, resulting in fewer clusters encountered from the same set of transects. Therefore, *I strongly recommend that either surveys be designed for the specific conditions expected to be encountered* or if the same set of transects will be used from year to year, design the survey so that adequate samples will be obtained even when the population is low or distributions shift. With an adequate transect grid, you should be able to detect gross changes in pronghorn distributions anyway. Survey designs can be improved based upon results of previous surveys. However, it is dangerous to assume that the same set of transects will be adequate in all cases unless the transect grid is very intensive.

**Estimating Flight Time and Costs:** It is frequently helpful to estimate the time and costs for conducting the survey. First you need to obtain estimates for the following:

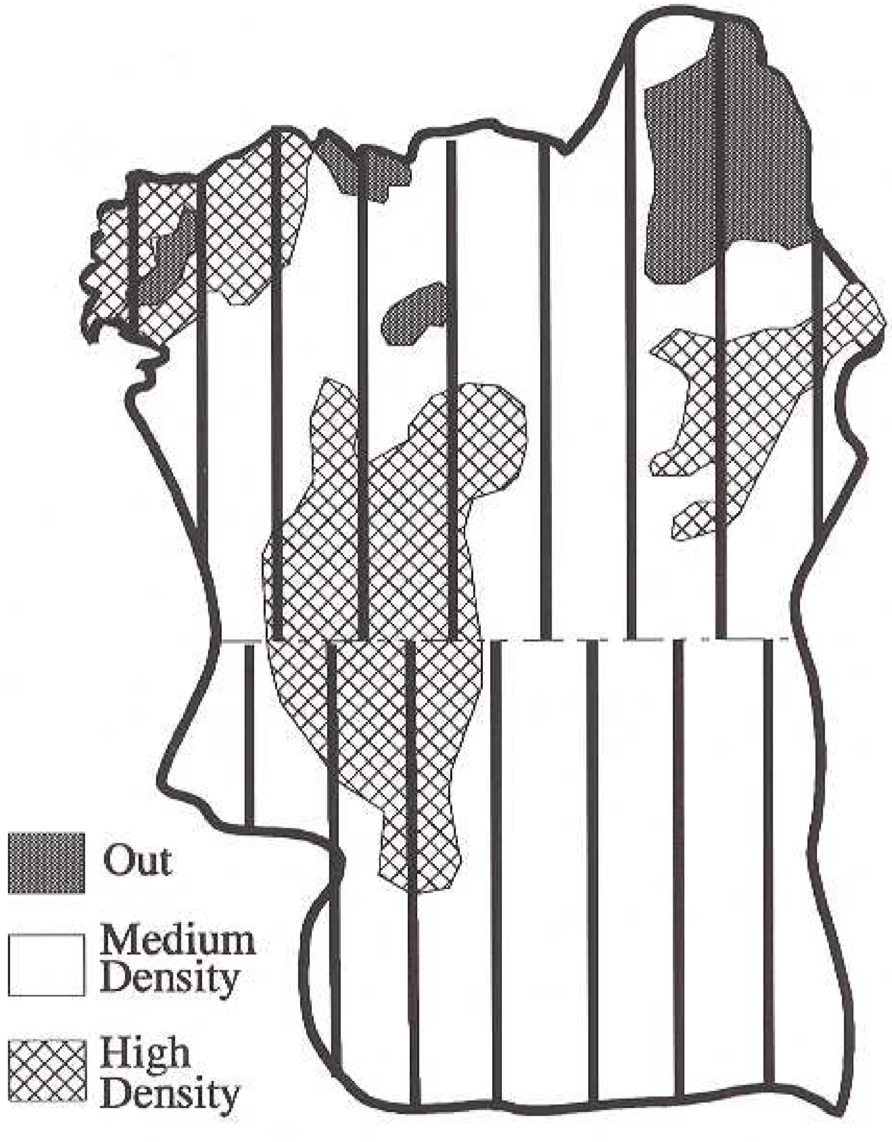


**Figure 3.4. Example transect layout using two blocks to eliminate long transects (see text).**

1. Total line length, *L*, for the transects: Using one of the methods above, estimate the total transect length you need to survey.
2. Total distance between transects: Estimate the total distance to be flown between all transects for the survey. Usually this is the width of the survey area perpendicular to the orientation of transects. Where the survey area is split into sets, add the additional distance to go between transects for both sets.
3. Charter rates: Obtain the charter rate for flying the survey and the ferrying rate if different from the charter rate.
4. Ferry time: Estimate the amount of flight time to get the plane from its home airport to the airport from which the survey will be flown and back. In some cases, the ferry time may be from another airport to the base airport for the survey and then on to another survey area.
5. Transition distances: The transition distances are the average distances to and from the study area and the base airport for each survey session. If you break the survey into two 2-hour surveys, then double the transition distances. Add in any planned practice runs prior to starting the actual survey. For example, if you must fly 30 miles to the study area then the transition distance is 60 miles. If you plan to fly 2 sessions, then the transition distance is 120 miles, etc.
6. Average ground speed: The ground speed can vary during the survey and may exceed 100 mph. However, it is good to be conservative and plan for a slower speed for estimating costs. This allows for additional flight time for turning, circling back, landing to take a break or flying into a headwind.
7. Overnight charges: In many cases, the pilot may need to stay overnight. Providers of aerial line transect services usually charge an additional fee for overnight stays. These can be added into the costs for the survey.

Example:

Suppose you estimated that you need to fly 350 miles of transect in a particular herd to obtain the desired sample size. The study area averages 25 miles across. To avoid overly long transects, you split the survey area into two blocks. You must fly an average of 15 miles each way to get to and from the first block and 22 miles for the second block. Each block can be completed in one session. The pilot will stay over one night. The first day, you fly an additional 20 miles of transect as a training run. It will take 2 hours for the plane to get from its home airport to the airport that you plan to fly the survey out of and another hour to ferry the plane to the next area. You expect the plane to conservatively average flying about 85 mph. Ferry time costs $150/hour and survey time costs $200/hour. Each overnight stay costs $60. Here are the cost estimates:

| | | | |
|---|---|---|---|
| Ferry Time: | 3 hours * $150/hour | = | $450.00 |
| Survey Time: | (350+50) miles/85 mph * $200/hour | = | $941.18 |
| Transition Time: | (30+20+44) miles/85 mph * $200/hour | = | $221.18 |
| Overnight Charge: | 1 night * $60/night | = | $ 60.00 |
| | TOTAL SURVEY COST | = | $1672.36 |

## OTHER CONSIDERATIONS IN THE DESIGN OF BASIC SURVEYS

Prior to conducting the survey, a number of issues need to be decided since these have a bearing on how the data are collected. Be sure the observers and pilot have been advised of the criteria to be used and be sure to make note of these so that the proper analysis will be conducted.

**1. Handling cluster size:** Decide how you plan to handle cluster size bias in advance so that observers can be properly instructed as to how to collect data. These are described in detail in the next chapter on conducting the survey. There are two general approaches as discussed below:

> **a. *ad hoc*** - The *ad hoc* approach assumes that mean cluster size will be determined within the first two distance bands on either side of the plane. This assumes that cluster size bias is negligible within this narrow interval (50 m). This approach has the advantage of allowing observers to visually estimate the size of clusters farther out rather than divert attention to count animals in them.
> **b. size-bias regression** - If you plan to use one of the size-bias regression approaches implemented in the DISTANCE program, then observers should be instructed to count the individuals in each cluster.

The regression approach in DISTANCE is generally the preferred option. On some surveys, cluster size bias is significant within 50 m of the line.

**2. Handling variation in height AGL:** As the plane's height deviates from the planned survey height above the ground, the area on the ground defined by the plane's strut marker system on the plane varies. It is important to control for this source of error by adjusting distance bands for actual height above ground level (AGL). Persons recording data on surveys need to know how these will be measured in advance. There are two basic approaches to doing this, depending upon the availability of equipment on the airplane:

> **a. actual measurements for each position** - Using a digital radar altimeter, record the height above ground at each position on the line perpendicular to where pronghorn are observed. The radar altimeter reading will be used to adjust the midpoint of the distance class for each observation prior to analysis. The midpoint assumes the detection curve is uniform within each distance interval. Theoretically, there is a portion of the declining detection curve within each distance interval. However, using mid-points seems to work in practice. Because the survey should be conducted so as to have a flat detection curve near the line where it is most important, the mid-point approach seems reasonable.
>
> **b. averages of end-points and/or random measurements** - Where it is not feasible to record height AGL for each observation, record these at transect end-points and/or at systematic or random intervals along the line. Transect end-points may not give true estimates where the endpoint coincides with drastic changes in elevation (e.g., a cliff, river in a canyon). The heights AGL will subsequently be averaged to adjust the width of distance bands for the survey as a whole rather than for each observation.

## INTRODUCTION TO SPECIAL SURVEY DESIGNS

The basic survey design described above (systematic with a random start), should be viewed as an initial starting point for designing surveys for particular herds. It is most useful when little is known about the distribution and dynamics of a particular herd. However, that approach may not be adequate for some situations. In some cases, improvements in the survey design can increase precision for a given level of effort. This section introduces some other considerations in survey design and hopefully points potential users to specific references for guidance. Users contemplating advanced designs should consult with biologists and statisticians who have experience with advanced designs for line transect surveys.

### Stratification

Stratified sampling is commonly used in aerial surveys for wildlife abundance (Caughley 1977b, Gasaway et al. 1986, Guenzel et al. 1986, Unsworth et al. 1994). Reasons for stratifying include the need for separate estimates and confidence intervals for each subpopulation, differing sampling problems among strata, improving precision of estimates, and administrative convenience (Krebs 1989). The sampling scheme within strata can be systematic or random. For most aerial surveys using fixed-wing aircraft, systematic sampling using a random start is preferred from a logistical standpoint. Stratification may not always be practical, however (Burnham et al. 1980:201)

The basic idea behind stratified sampling to improve precision is to break the study area up into strata which are fairly homogeneous within but vary considerably among each other. You are not penalized for the variation among strata. In practice, identifying meaningful strata boundaries can be problematic. In pronghorn surveys, this means identifying strata which are more uniform in the density and distribution of animals internally compared to the density among strata. Survey effort among strata should be allocated proportional to abundance since the variance within a stratum is proportional to abundance (Norton-Griffiths 1978, Buckland et al. 1993:99). One problem with stratified surveys is that wildlife populations are mobile (Gasaway et al. 1986). Thus, the distribution of pronghorn clusters can change over time. If stratification is intended to improve precision, a preliminary reconnaissance survey may be needed to verify pronghorn distributions. In some instances, strata boundaries may be different from survey to survey.

Sometimes, stratification is used to provide estimates and confidence intervals for specific subunits of interest such as individual hunt areas. There are a number of analytical approaches that can be used. The intended use of the data may dictate the appropriate choice of one method over another.

In many herds, some areas can be stratified as "unoccupied" habitats where the density is assumed to be zero. These areas are excluded from the survey allowing more resources to better survey the occupied habitat. This can be quite helpful for lower density populations where it takes more effort to obtain an acceptable sample.

There are two basic approaches to the analysis of stratified surveys of particular interest to aerial line transect sampling. Each has certain advantages over the other. Both approaches relate to how the density correction factor, $f(0)$, is applied to the estimate for each strata:

1. **stratum $f(0)$** - An independent estimate of density or total numbers is obtained for each stratum using a specific estimate of $f(0)$ derived from the data for that stratum. This approach allows detectability to vary among strata. However, it typically requires large samples within strata. In some strata, densities may be too low to obtain adequate sample sizes within them for the allocated budget.
2. **pooled $f(0)$** - In some cases, you may be interested in obtaining an estimate of density or total for individual strata but you do not need or can't afford to put the effort into sampling the strata intensively enough to obtain a unique correction factor. In those situations, you can estimate the density for each stratum using a pooled $f(0)$ estimated across all strata. This allows reasonable estimates of individual strata where sample sizes may be small. However, it assumes that detectability is the same across strata. In many cases, this is a reasonable assumption. The counts may vary among strata because of differences in density but detectability is the same. Often strata are contiguous so viewing conditions are similar in adjacent strata. Distance sampling is robust to pooling (Burnham et al. 1980, Buckland et al. 1993).The overall estimate may be okay but estimates for individual strata may be wrong.

The analysis program, DISTANCE (Laake et al. 1996), allows the user to specify the resolution at which detection probability is calculated.

**Post-stratification -** In most cases, designing and conducting a stratified survey from the start is superior to post-stratification. However, post-stratification can be helpful in limited circumstances (Buckland et al. 1993:308) to reduce bias (Anganuzzi and Buckland 1993). Locational data on observations obtained during aerial pronghorn surveys can be analyzed using Geographic Information Systems (GISs) or other analytical tools to help define strata after the survey. When used, post-stratification should be based on something other than density. Users should consult statisticians on the appropriateness of post-stratifying their survey data.

Where specific estimates for certain regions are desired, you can go back and determine the number of clusters and line lengths within each stratum and apply a pooled correction factor (see pooled $f(0)$ above). This can be done with DISTANCE by reassigning portions of transects and associated observations to strata and rerunning the analysis.

**Strategies for Low Density Herds**

For small herds, the sampling intensity required to meet minimum sample sizes may be prohibitive, particularly where conservative management strategies and other constraints are already in place. Some herds may also have a great deal of interchange with other populations and fluctuate more widely. The precise estimation of small populations has always been difficult and/or expensive.

The question is one of how badly you need to obtain a precise estimate of the population. You should first consult a statistician with experience in line transect sampling in these situations.

There are different ways to get estimates for low density populations and other special cases short of performing an intensive survey. Two strategies for estimating low density herds from line transect surveys are described here. One is analogous to the pooled $f(0)$ approach described above. The other involves sampling with replacement.

1. **pooling** - This approach is identical to using a pooled $f(0)$ for a stratified survey as described above. By piggybacking the survey with one for an adjacent, larger population, you adjust the observations for the smaller herd using the pooled correction factor for both areas. This again assumes that dectectability does not vary between the two herds. However, it allows you to obtain a corrected estimate without putting as much effort into sampling as would be required to estimate the herd separately.
2. **sampling with replacement** - Where more reliable estimates are required, sampling with replacement may sometimes be appropriate. For some small populations, you may not be likely to obtain an adequate sample even if you completely cover the area (i.e., attempt a census). Sometimes it is difficult to accurately fly a complete coverage survey. Because population totals estimated using line transects are based on multiplying density by the area, repeated sampling effort will improve the density estimate that can be applied to the survey. This is again analogous to the pooled $f(0)$ approach described above, but "strata" in this case are different time occasions. This assumes detectability doesn't vary over the period repeated surveys are performed. This may be reasonable if the replicate surveys are conducted in a relatively short period. The analysis of this type of survey will require some adjustments and it is best to seek advice from an experienced statistician before initiating such a survey. In some cases, using a finite population correction may improve the estimated variance.

**Some Advanced Topics**

Line transect sampling continues to be refined. Users should keep appraised on new developments. The following are some topics where additional improvements may occur:

**Using Covariates:** In some instances, ancillary information can be used to improve estimates, particularly if not all animals on the line are detected. The procedures described in this manual explicitly consider the covariate of cluster size in the analysis (Drummer and McDonald 1987, Thompson 1992:204, Buckland et al. 1993:102). Other factors that can influence the detection probability can be incorporated into the design of surveys (Burnham et al. 1980). Quang and Becker (1996) proposed a method to incorporate covariates using loglinear functions. Covariates are more commonly used in studies of marine mammals (e.g., Laake et al. 1997). There does not appear to be a need to incorporate other covariates in most aerial line transect surveys to estimate pronghorn population sizes in Wyoming provided surveys are properly conducted to meet assumptions. Should circumstances warrant, there are ways to include other covariates in the analysis.

**Adaptive Sampling:** Adaptive sampling is a relatively new approach for improving estimates over conventional sampling for a given sample size or cost (Thompson 1992). In conventional sampling, sample units are usually selected prior to the survey and do not depend on observations made during the survey (Thompson 1992). However, adaptive sampling allows the selection process to depend upon values of the variable of interest observed during the survey (Thompson and Seber 1996, Thompson 1992). The sampling plan can change during the survey based on observed patterns in the population, thereby reducing the amount of sampling in low-abundance areas (Thompson and Seber 1996). Adaptive sampling may not always improve precision over conventional sampling designs (Conroy and Smith 1994). It appears to be most promising for quadrat studies where populations are highly clustered. The suitability of adaptive sampling to aerial line transect surveys is probably not worth the effort for Wyoming pronghorn surveys.

**Statistical Power:** For some study objectives, it is desireable to design surveys that can detect a specified effect level (e.g., land use impact, harvest management, winter mortality, etc.). Alternately, it can be helpful to determine the statistical power of existing surveys to know whether or not they are sensitive enough to detect a specified change (e.g., a 10% decrease in population size). For example, the statement that one can reliably measure a 10% change from a herd's population objective using existing management techniques is usually indefensible. However, one can evaluate the sensitivity of existing surveys. PASS, a power and sample size program (Hintze 1991), has been used to estimate power for some Wyoming pronghorn surveys (Guenzel 1994). Power is primarily of concern to specific research studies rather than to management surveys.

**Spatial Patterns:** The development and availability of GISs allow spatial patterns from line transect surveys to be evaluated. Positional data (e.g., UTM coordinates) for observations can be used in refining strata boundaries for future surveys, post-stratification (Buckland et al. 1993:308), evaluating changes in spatial distributions among surveys or examining spatial autocorrelation (Odlund 1988, Cressie 1991). Spatial patterns can be considered in the design of surveys (Thompson 1992).

## CONCLUSION

Properly designing efficient surveys is one of the most important tasks in estimating pronghorn abundance using aerial line transect surveys. While simpler designs have great appeal, users should avoid the trap of "doing what you did before" in the design of surveys. Populations are dynamic over space and time. What may be an adequate design at one time may not be adequate later. Users should continuously monitor results of ongoing studies and make adjustments where needed. Some important aspects of survey design are clearly defining the objective, identifying the target population, and recognizing survey limitations. A good survey design must be properly implemented. The next chapter describes those aspects.