1. Distance Sampling And Desert Tortoises

Although it is easy to assume that enumerating a sedentary animal (desert tortoises) in the relatively open habitat of the Mojave Desert would present few problems, this assumption is not supported by experience. Desert tortoises are sparsely distributed and a certain number are underground and not visible at any time. When they are out of their shelters, they are cryptically colored and shaped. Their behavior also does not draw attention to them. Distance sampling methods are therefore employed to correct our population estimates for the proportion that were hidden and not visible, and for the proportion that were not detected although they were on the surface.

Logistic considerations also affect our ability to estimate population size in desert tortoises. Desert tortoise populations are not dense and the area to be sampled is vast, resulting in the need for a large number of transects to provide an adequate sample size. The optimum period for sampling is brief (about 8 weeks), so this project is a large scale effort that must be mobilized and completed in a very short time frame. Many transects will be in terrain that is physically challenging, and tortoises are not found on all transects. This challenges observers to remain alert and attentive to the details of the methods. Departures from the methods can result in poor-quality data that lead to biased estimates. The ability to conclude anything about the status of the desert tortoise with any confidence depends on trainees performing to the best of their abilities in both the training and data collection phases.

Objective 1: Understanding how data collection affects precision and bias of the density estimate.

Objective 2: Understanding how different types of field data contribute to calculation of the density estimate.

This section includes a rudimentary introduction to distance sampling theory and a more detailed discussion of some of the specific issues involved in using distance sampling to estimate abundance of desert tortoises. For more information on the theory and general use of distance sampling, consult: *Buckland, S.T., D.R. Anderson, K.P. Burnham, J.L. Laake, D.L. Borchers, and L. Thomas. 2001. Introduction to Distance Sampling: Estimating Abundance of Biological Populations. Oxford Univ. Press, Oxford. 432 pp.*

Objective 1: Understanding How Data Collection Affects Precision and Bias of the Density Estimate

Precision and Bias

The methods involved in monitoring desert tortoise populations have two immediate objectives: to maximize precision and to minimize bias. Precision represents the amount of uncertainty (variance) in the estimate of abundance. If there is too much variance in annual estimates, the ability to draw conclusions about the magnitude or direction of change from year to year is diminished. Adequate precision in studies of wildlife abundance usually cannot be achieved with small samples. Therefore, a large number of biologists walk thousands of kilometers in the Mojave Desert each year to sample tortoise populations. Because precision is largely a function of effort, it is relatively immune to the influence of training. Training is more important for minimizing the bias in the estimates of tortoise abundance.

Bias is the deflection of the estimated abundance from the true abundance and can be either negative (the estimate is lower than the true abundance) or positive (the estimate is too high). It can result from both the methods employed and the set of samples used to collect the data. The first step in combating bias is a good study design. All unbiased monitoring of animal populations requires some form of randomization so that the samples are independent of the distribution of the animals. For example, the estimates of tortoise abundance would have positive bias if transects were conducted only in areas known to have large populations of tortoises. The locations selected each year for transects are designed to be as free as possible from sampling bias, so every effort should be made to conduct each transect at the selected location, and any rejected locations must be well justified. Bias can also result from improper methods or correct methods improperly applied. Training teaches the methods used to sample desert tortoises, but it should also make crews aware of the importance of following correct procedures and the larger consequences of poor quality data collection.

Desert tortoise monitoring uses the line transect method, a modification of the strip transect method, where an observer travels down the centerline of a strip of defined length (L) and width ($2w$, where w equals the distance from the center to the edge of the strip) and records every object observed (n). Density (D) is then simply n divided by the area searched ($2wL$) (Fig. 1). This method assumes that all objects within the strip are located. If objects within the strip are not counted (Fig. 2), the density estimate will be too low (negative bias). In practice, some objects will be missed, and with a simple one-time count of the strip, there is no way to estimate the magnitude of the bias. Additional logistical problems, such as

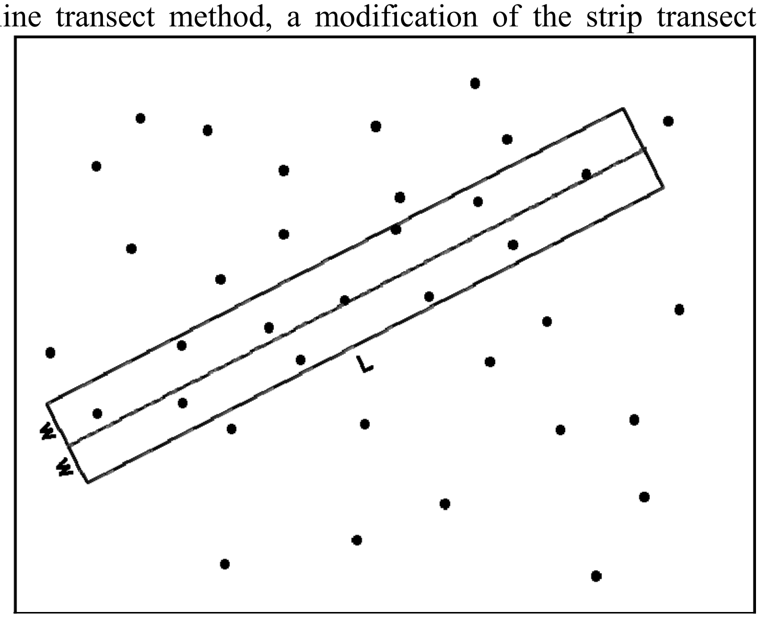

Figure 1. Hypothetical strip transect of length L and width 2w. Eleven objects are counted in the transect, giving density $D = 11/2wL$.

accurately defining the width of the strip, make this method impractical in most cases, especially for animals like desert tortoises that are sparsely distributed in large landscapes.

Objective 2: Understanding How Different Types of Field Data Contribute to Calculation of the Density Estimate

Correcting Population Estimates to Reflect Imperfect Detection

The line transect method essentially adds only one piece of data to the observations in a strip transect, the perpendicular distance (*d*) from the center of the transect to the object detected (Fig. 3). **Because objects close to the line are more likely to be detected than are objects farther from the line**, the distribution of detection distances can be used to estimate a probability of detection ($\hat{P}_a$) within a given distance *x* from the transect centerline. One critical assumption in this method is that all objects on the transect centerline are detected, or the probability of detecting an object at distance 0, $g(0) = 1$. If this assumption is met, then the estimate of density takes the general formula:

$$\hat{D} = \frac{n}{2wL \cdot \hat{P}_a},$$

where $\hat{P}_a$ is the probability of detecting a tortoise within *w* meters of the transect line. To estimate $\hat{P}_a$, a curve is built describing the function *g(x)*, the probability of detection at distance *x* (Fig. 4). This curve is derived from the distribution of observed perpendicular distances out to a maximum distance *w*, which defines the strip width of interest. Figure 5 illustrates our expectation that all tortoises on the transect line ($g(0)$) are detected, but tortoises farther from the line are less visible.

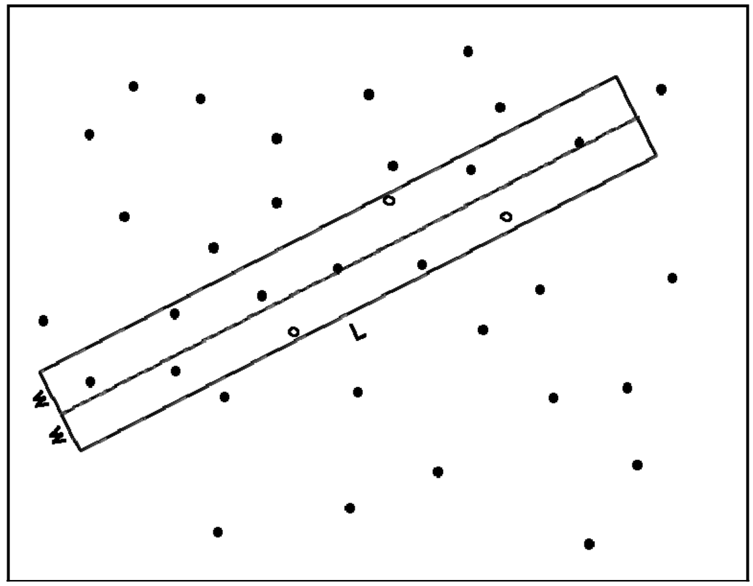

Figure 2. Same example as in Fig. 1, except that 3 objects have been missed (unfilled circles). The density estimate is now D = 8/2wL and has 27% negative bias. Note that objects farther from the centerline have a greater chance of being missed.

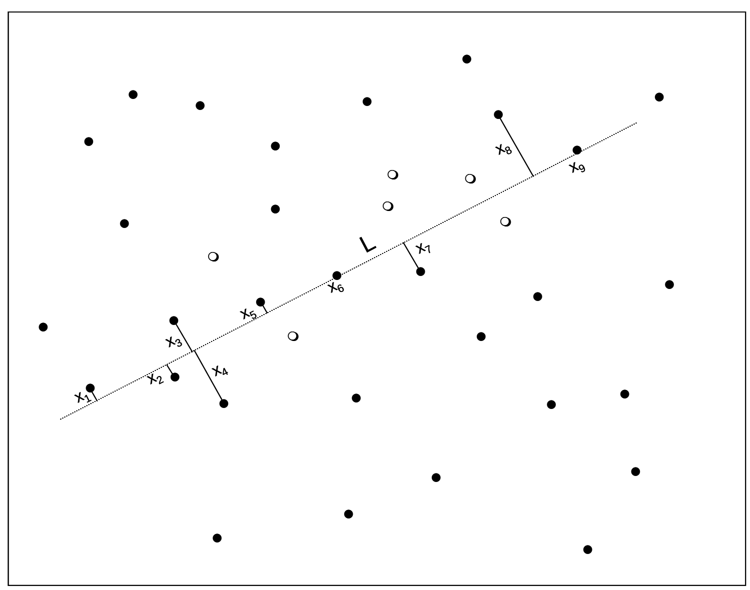

Figure 3. Line transect of length L. Nine objects at distances x_1, x_2, … x_9 from the line were detected. Six objects (unfilled circles) within the farthest observed distance (x_8) were missed. After Buckland et al. (2001), Fig. 1.2.

There is no reason to expect fewer tortoises to occur farther from the line, so we interpret the graph to mean that if we had perfect vision, we could see all the tortoises represented by the rectangle (1.0 · *w*) in Figure 5. Instead, we only see a certain proportion, $\hat{P}_a$, which is the proportion of that rectangle that is represented by the shaded area under the curve. In essence, the density of the detected objects is used to estimate the density of the undetected (missed) objects, and these two quantities together estimate the true density.

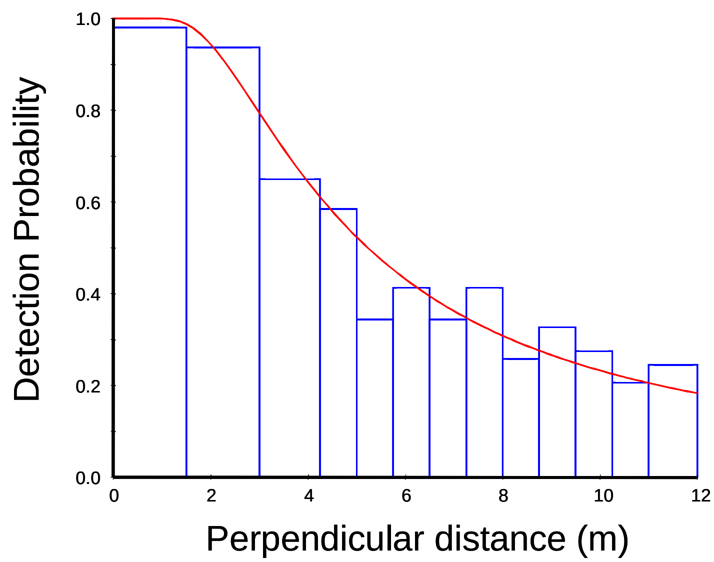

Figure 4. Histogram of observations and detection function to 12m for adult tortoises in the Mojave Desert in 2005.

As an example, in a given year, we might walk 8000km (*L* in the density equation above) and report seeing 100 tortoises (*n*) within 20m of the transect line (*w*), but estimate that we only detected 50% of the tortoises that were present ($\hat{P}_a$). Without correcting for detection, we would estimate there are 100/(2*0.02*8000) = 0.312 tortoises per km^2. However, adjusting for detection in the equation above, we refine our estimate to 0.625 tortoises per km^2.

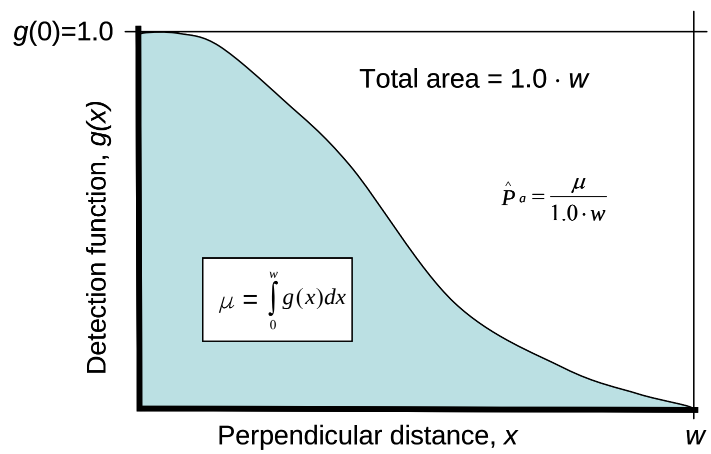

Figure 5. Probability of detecting an animal within distance *w* of the transect centerline is the area under the curve (modeled from the distribution of observed perpendicular distances) divided by the total area of the rectangle 1.0·*w*. After Buckland et al. (2001), Fig. 3.1.

<u>Assumptions of Distance Sampling</u>

In addition to the assumption that all objects on the line are detected, two additional conditions need to be met for unbiased density estimation using distance sampling: objects are detected at their initial location, prior to movement in response to the observer, and perpendicular distances are measured accurately. Fortunately, in using line transect methods for desert tortoises, these conditions are relatively easy to meet. Desert tortoises generally do not move rapidly in response to approaching observers, except sometimes when retreating into a burrow. In this case, the distance should be measured to the point where the tortoise was first seen. Perpendicular distances can be accurately measured, particularly if the transect centerline is clearly marked (Anderson et al. 2001), but the method used for desert tortoises does not use a marked centerline and satisfying the second condition requires careful application of the field protocol.

Line transects for desert tortoises typically produce data suitable for generating detection functions (Fig. 5). However, these data alone do not result in unbiased estimates of abundance. Both training and field data show regular violation of the assumption that $g(0) = 1.0$, that all tortoises on the transect centerline are detected. Some tortoises on or very near the line will be missed, despite being available for sampling (see below). This can happen for a number of reasons, perhaps because a tortoise was hidden from view on the far side of a shrub or because the observer was momentarily inattentive. If the number of tortoises missed cannot be estimated, then the estimate of abundance will underestimate true abundance and the magnitude of this negative bias will be unknown and unknowable. To address this problem, a dual-observer technique can be used. Transects are conducted by two observers who search for tortoises independently, which allows a detection probability to be computed for tortoises on (or very near) the transect centerline. If needed, a correction factor can be applied to the estimates of abundance.

Proportion of Tortoises That Are Not Available for Sampling

Thus far, we have discussed the role *distance* plays in making cryptic tortoises more or less detectable. A larger source of negative bias results from the basic *natural history* of desert tortoises. Tortoises spend a considerable proportion of time underground in burrows or in vegetation, sometimes deep enough that they are not visible to personnel conducting transects. This proportion of the population not available for sampling varies from year to year. If this proportion is not accounted for, then estimates of abundance will underestimate true abundance. Worse, estimated abundance will vary among years, probably in ways that bear no relationship to variation in true abundance, and there would be no ability to know the magnitude of the negative bias. Fortunately, if the proportion of the population available for sampling can be known or estimated, distance analysis allows the estimate of abundance to be adjusted.

Focal tortoises equipped with radio transmitters are used to estimate the proportion of tortoises visible to sampling each year (see Chapter 6). This parameter, G_0 (pronounced, G sub-zero), should not be confused with $g(0)$ (pronounced, g at zero) the probability of detection at distance = 0. Estimation of G_0 consists of the observation of a cohort of focal tortoises in each monitoring stratum. The focal animals are equipped with radio transmitters and observed daily while transects are being sampled in that area. Information is recorded on tortoise location and visibility. Typically, at any time during the optimal time of day, 80% of tortoises are above-ground or visible in burrows. This means that even if we adjust our density estimate to correct for lower probability of detection farther from the transect centerline, we are still underestimating the density of tortoises by 20%. To account for this "invisible" portion of the population, we use the following equation:

$$\hat{D} = \frac{n}{2wL \cdot \hat{P}_a \cdot \hat{G}_0}.$$

Starting from our example above, with 0.625 tortoises/ km^2, we can now consider the significance if only 80% of the tortoises were available to count. Using the equation above, we estimate there were 0.625/0.80 = 0.781 tortoises/km^2.

Figure 6 depicts this new information. The larger square of the graph represents the actual size of the population. The proportion described in Fig. 5 and encompassing the rectangle with an area of $1.0 \cdot w$ is only the visible portion of the total population. This visible portion comprises two parts: The proportion we see is the area under the curve in green. The proportion that is visible but undetected (due to distance from the transect line) is in white. Finally, the portion of the total population that we discuss in this section and that is invisible in burrows is the additional area in orange.

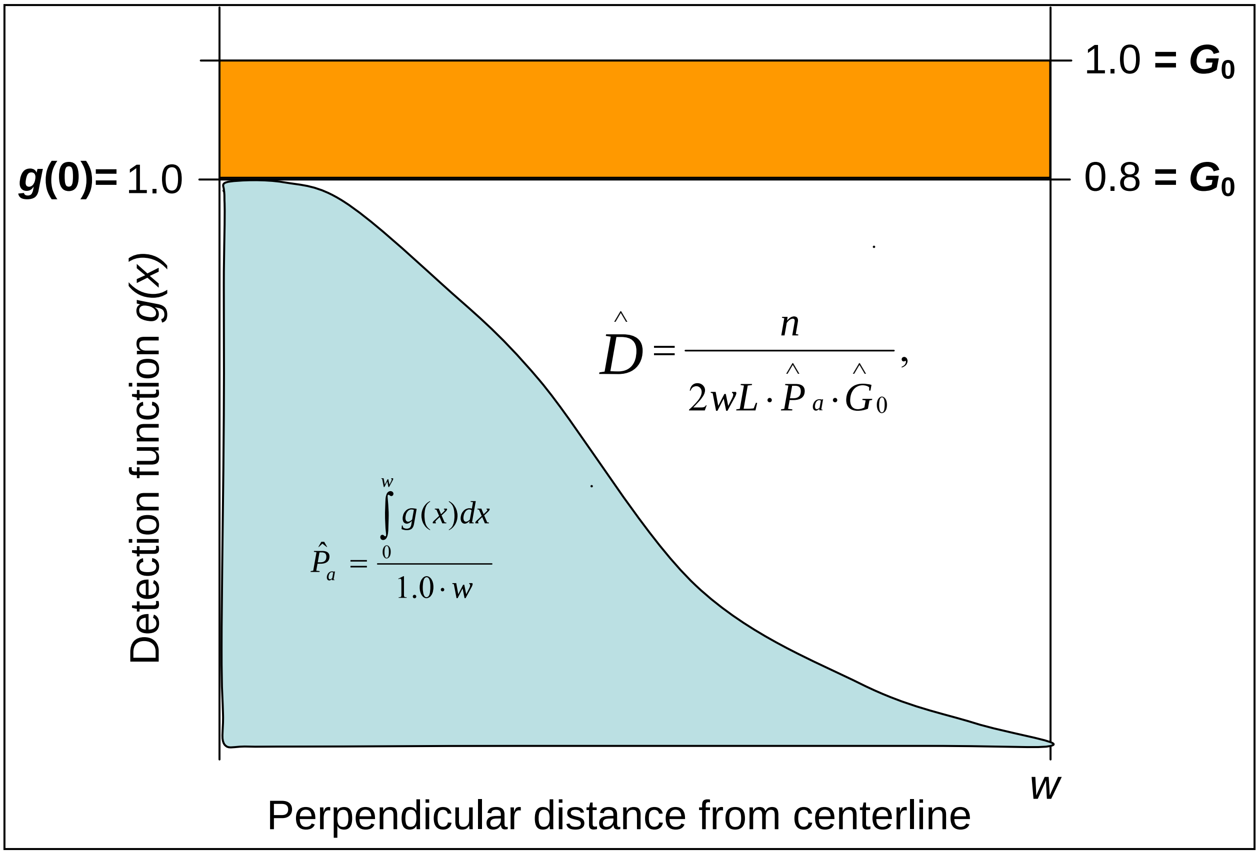

Figure 6. Probability of detecting a visible animal within distance *w* of the transect centerline is the green area under the curve divided by the total area of the rectangle 1.0·*w*. The rest of that rectangle (in white) is visible but undetected because as cryptic animals like tortoises are farther from the observer, they are harder to detect. This rectangle is the visible portion of the total population (the larger rectangle), which includes tortoises invisible in burrows (the orange rectangle).