**Commonwealth of Massachusetts**
**Division of Fisheries and Wildlife**

dcr Department of Conservation and Recreation

# Estimating White-tailed Deer Abundance at the Blue Hills Reservation using Distance Sampling

Technical Report - November 2013


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Photo taken by Bill Byrne

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## Acknowledgments

Abundance surveys in the Blue Hills Reservation were a coordinated effort between the Commonwealth of Massachusetts Division of Fisheries and Wildlife and the Department of Conservation and Recreation. I would like to give a special thanks to Alexandra Echandi, Natural Resources Specialist with the Department of Conservation and Recreation, for her exceptional effort to ensure that surveys ran smoothly.

## List of Acronyms

| | |
|---|---|
| AIC | Akaike's Information Criterion |
| ATV | All-terrain Vehicle |
| CI | Confidence Interval |
| DCR | Commonwealth of MA Department of Conservation and Recreation |
| DFW | Commonwealth of MA Division of Fisheries and Wildlife |
| GIS | Geographic Information System |
| MA | Massachusetts |
| MCDS | Multiple Covariate Distance Sampling |
| WMZ | Wildlife Management Zone |

# Introduction

The abundance of white-tailed deer (*Odocoileus virginianus*) in the Blue Hills Reservation, a 7000-acre state park owned and operated by the Department of Conservation and Recreation (DCR), has never been empirically estimated. The Division of Fisheries and Wildlife (DFW) uses a harvest-based estimator to model deer density for 15 Wildlife Management Zones (WMZ) across the commonwealth, such that the density estimate for WMZ 10, where the Blue Hills is located is approximately 25-35 deer per square mile of forested land. However, because hunting is prohibited in the Blue Hills, we believe deer density may be much higher than DFW's estimate. Quantifying deer density in the Blue Hills Reservation is important for managers of the reservation within the DCR to establish baseline information for future management decisions. Deer density estimates for the Blue Hills Reservation are important for DFW because they can be used to provide an independent density estimate at a small scale that can be extrapolated to similar lands in WMZ 10 that are closed to hunting.

## Distance Sampling

Distance sampling using line transects is a generalization of the strip transect sampling method, in which all objects within sample strips are detected (Buckland et al. 2001). Distance sampling allows a proportion of objects to be missed away from the line or transect, thus allowing a wider strip to be sampled and increasing sample size and efficiency (Buckland et al. 2001). Distance sampling often provides a practical, cost-effective method of estimating density for a broad range of applications, from walking transects to detect inanimate objects or plants in a terrestrial setting to traversing transects in a ship to detect moving objects such as whales in a marine setting (Thomas et al. 2010).

The distance sampling estimator is more appealing than estimators that require marked animals (mark-recapture methods) because animals do not need to be captured or handled, allowing the method to be far less expensive when used to estimate population size. Also, distance sampling is more applicable to a wider range of species and areas of inference than harvest-based models because removals are not required.

However, assumptions may be difficult to meet to obtain unbiased population estimates of highly mobile animals such as deer (Buckland et al. 2001, Koenen et al. 2002, Fewster et al. 2008). Assumptions include: (1) surveys are conducted from randomly-placed points or transects; (2) all objects on or near a point or transect are detected with certainty; (3) objects are detected at their initial location and any movement prior to detection is independent of observers; and (4) measurements are accurate (Buckland et al. 2001). Most assumptions can be met easily when applying distance sampling methods to count dung (Buckland et al. 2001, Marques et al. 2001). However, accuracy of density estimates rely on estimates of both defecation rates and dung decay rates, which often are estimated using penned deer, and can vary spatially, seasonally, and by differences in feeding behavior related to sex and age (Van Etten and Bennet 1965, Mitchell et al. 1985).

Common methods of ground navigation of random transects or points include walking, horseback, and all-terrain vehicles; but these may result in deer moving in response to observers before detection, which results in negatively biased estimates of density (e.g., see Koenen et al. 2002). Aerial surveys can avoid the problem of deer movement in response to the observer, but are expensive, animals may move in response to a low-flying plane or helicopter, and it is difficult to ensure that all deer on the transect are detected, especially in forested landscapes (Naugle et al. 1996, Haroldson et al. 2003, Thomas et al. 2010). Surveying from roads using distance sampling is a convenient and commonly used method (e.g., Gill et al. 1997, Heydon et al. 2000, Koganezawa and Li 2002**,** Ruette et al. 2003, Ward et al. 2004, Bates 2006), which can reduce movement in response to observers. However, roads are not random; thus, sampling from them violates the critical assumption of randomly placed transects and can result in biased estimates of density, which may be unrepresentative of the population (Anderson 2001, Buckland et al. 2001). Furthermore, if the distribution of deer was correlated with the location of roads, then the estimator for detection probability may be biased, leading to a biased estimator of density. The direction of the bias would depend on whether deer were avoiding or selecting for areas near roads, and the magnitude of the bias would depend on the amount of non-uniformity of the distribution of deer relative to transects. Nevertheless, navigating existing trails or roads with vehicles at night using spotlights (deer eyes reflect light) seems to be the best balance of limiting bias when surveying highly mobile animals such as deer. Further, if the bias is constant from year to year, estimates can be used to accurately investigate trends.

## Study Area

We selected a representative sample of available roads and trails within and around the Blue Hills Reservation as transects for Distance Sampling Surveys (Fig. 1). We identified 14 survey routes or transects (Fig. 1) of similar length (range = 0.78–3.86 mi, mean length = 2.32 mi) rather than a few long routes to better estimate the variance related to encounter rate (Buckland et al. 2001). Approximately half of the transects were dirt trails and the other half were paved roads; however, we did not survey busy highways for safety reasons. Transects included only segments of roads where spotlights could be used and were considered deer habitat (e.g., sections near buildings, parking lots, open water, etc. were excluded). Approximately 80% of the study area was forested and/or shrubland and considered deer habitat. We used a GIS (ArcView 10.0, Environmental Systems Research Institute. Redlands, California, USA) to measure transect lengths.

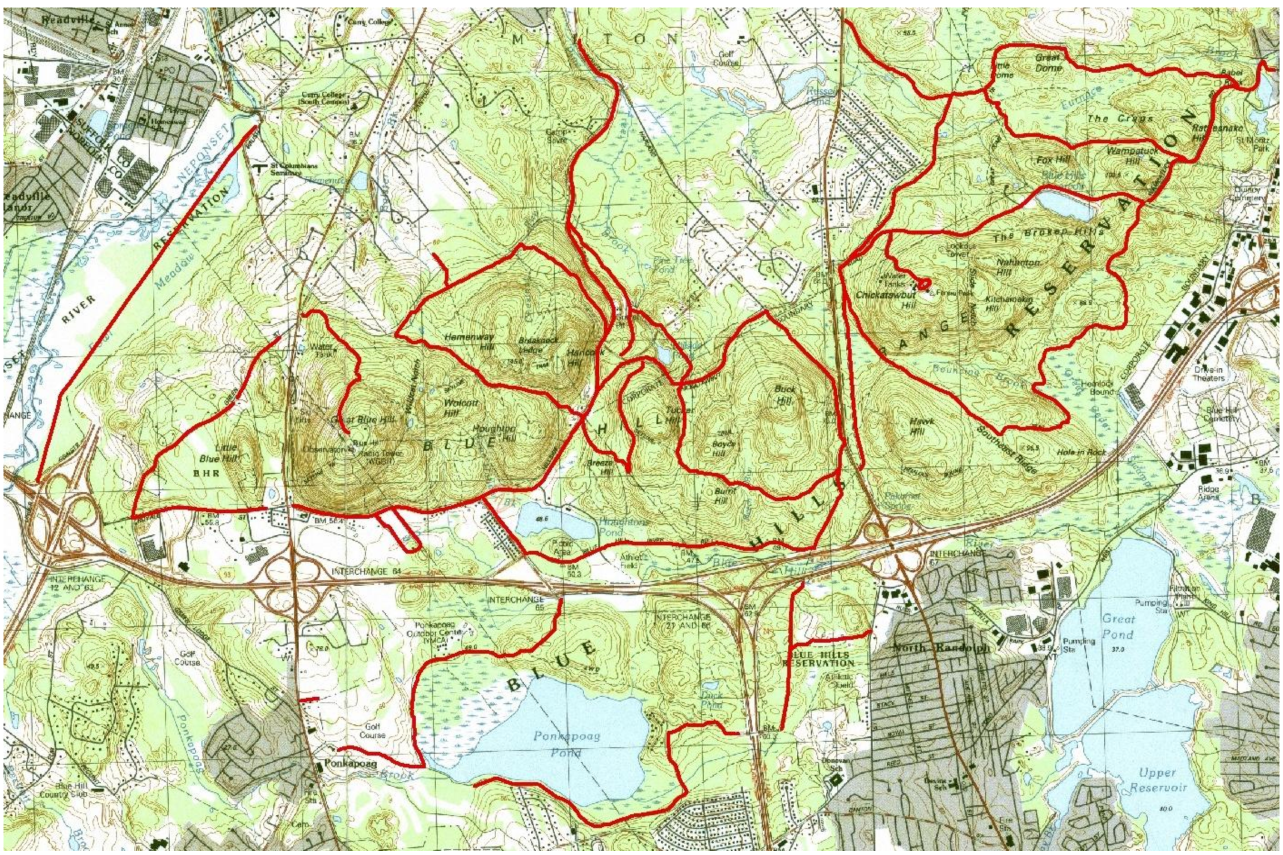


**Figure 1.** Map of the Blue Hills Reservation, in eastern Massachusetts, showing the transects used for distance sampling surveys in red.

# Methods

## Distance Sampling Surveys

We conducted distance sampling surveys prior to leaf-out in early May of 2013. We started surveys no earlier than 30 minutes after sunset, and surveys lasted approximately 4–6 hours. We used two crews to completely survey the study area in one night and repeated this for 3 nights to survey all transects 3 times, which ensured a large enough sample size of observations. One crew used a pick-up truck and traversed paved roads and wider trails and the other crew used an all-terrain vehicle (ATV) and traversed more of the smaller dirt trails. Each crew consisted of two observers and one driver. The observers illuminated their respective sides of each transect with handheld spotlights while standing in the bed of the pick-up truck or ATV.

We traversed transects at 5-10 mph and varied initial starting points to minimize temporal influences in deer detection that may have existed because of deer activity patterns. We did not survey on a particular night if adverse environmental conditions existed (wind $\geq$10 mi/hr, rain, visibility $\leq$1 mi).

When deer were detected, the driver recorded group size, perpendicular distance, and whether the deer were located in open or forested habitat (Appendix a). We defined groups based on behavioral cues and proximity to one another. Each deer in a group was no more than one-half the distance from the closest deer in its group than to the next closest deer of a neighboring group. We obtained perpendicular distance using a handheld laser rangefinder (LTI-TruPulse, Laser Technology, Inc., Centennial, CO, USA).

We used program DISTANCE (Thomas et al. 2010) to estimate density of deer groups and employed a size-bias regression method to model group size as a function of distance from the transect. If this regression was not significant ($\alpha = 0.05$), we used mean group size. Because the detection function is likely different for open areas than for wooded areas, we used the habitat type for each observation (open or forested) as a covariate, using multiple covariate distance sampling (MCDS). To account for differences in observer detection rates (see Diefenbach et al. 2003), we tested additional models including vehicle type and observer as covariates. We used both half-normal and hazard-rate key functions to model the detection function. We constrained models to use no adjustment terms to ensure the detection function was monotonically non-increasing (Marques et al. 2007). We used Goodness of Fit tests and Akaike's Information Criterion (AIC; Burnham and Anderson 1998) as aids in model selection for the detection function curve.

# Results

## Distance Sampling Data Analysis

Models including observer or vehicle type as covariates performed worse (based on AIC) than models including only habitat type as a covariate. The estimate of density, using MCDS with habitat type as a covariate and the half-normal key function, was 67 deer per square mile (Table 1, Appendix b) or 85 deer per square mile of deer habitat (85% Confidence Interval [CI] = 65 – 107), calculated by dividing the density estimate (Table 1 and Appendix b) by the proportion of the study area considered deer habitat (80% forested and other cover).

**Table 1.** Estimates of density ($\hat{D}$) of white-tailed deer with measures of precision from the May 2013 distance sampling survey, using habitat type (field or forest) of each observation as a covariate, Blue Hills Reservation, Massachusetts.

| Model[a] | $k$[b] | $n$[c] | $\hat{D}$ (deer/mi$^2$) | $E(S)$[d] | $\hat{P}$[e] | $\hat{D}$ 85% CI | CV[f] |
|---|---|---|---|---|---|---|---|
| hn | 2 | 129 | 67 | 1.93 | 0.51 | 52 – 86 | 0.17 |

[a] hn = half-normal key function
[b] $k$ = no. model parameters
[c] $n$ = no. of observed clusters
[d] E(S) = expected cluster size (mean cluster size or †size-biased regressed cluster size)
[e] $\hat{P}$ = detection probability
[f] CV= coefficient of variation

# Discussion

We observed fewer groups of deer near transects than slightly further away. Several studies using roads as transects with distance sampling also observed fewer detections near transects than expected for deer (*Odocoileus hemionus*; e.g., Rost and Bailey 1979, Kie and Boroski 1995; *Cervus nippon*; e.g., Koganezawa and Li 2002, *Capreolus capreolus*; e.g., Ward et al. 2004), moose (*Alces alces*; e.g., Yost and Wright 2001), and foxes (*Vulpes vulpes*; e.g., Heydon et al. 2000, Ruette et al. 2003), but were unable to definitively test why.

Fewer detections near the road may be for a number of reasons, including avoidance of the areas near roads (e.g., because of disturbance or correlation of habitat with roads; Fewster et al. 2008), movement away from roads in response to observers, or missed observations near roads (Buckland et al. 2001). Stainbrook and Diefenbach (2011) observed fewer deer near transects during surveys (from GPS collar locations) likely because of avoidance of areas near roads rather than movement in response to observers. However, we cannot rule out movement of deer in response to our vehicles in the Blue Hills Reservation because we did not have GPS-collared deer to investigate their movement. On the other hand, we rarely observed deer moving in response to our presence (most deer were bedded) and observers were trained to always look ahead to ensure all observations on the transect were detected and that observations were recorded at their initial location. Regardless of the reason, a lack of observations near roads would lead to positively biased estimates of detection probability because the fitted detection function is flatter than actual, leading to negatively biased estimates of density or estimates of density that are lower than actual.

## Conclusions

There is no perfect solution for meeting all assumptions of distance sampling when surveying for highly mobile animals such as deer. Even if completely random transects are used, it is difficult to detect all animals on the transect from aerial surveys (Fewster et al. 2008) and walking transects often results in avoidance of the observer (e.g., Koenen et al. 2002). Additionally, as discussed in Buckland et al. (2001) and Fewster et al. (2008), the use of non-random roads or tracks as transects for distance sampling can result in considerable bias because roads may affect the distribution of animals. An inaccurate or biased estimator with good precision, such as distance sampling, may be more useful for management and predicting trends than an accurate estimator with poor precision. Additionally, the logistical advantages of using roads as transects may outweigh disadvantages (Heydon et al. 2000). Nevertheless, any study using roads or tracks as transects with distance sampling should carefully consider and explain the effects of bias. For instance, if roads are used as transects and animals avoid roads, abundance estimates should be interpreted cautiously (considered conservative estimates), but can be very useful if treated as indices of abundance. For example, the true density may not be known exactly, but if the bias of deer movement is consistently causing estimates to be 20% low each year, plotting those estimates over time can be very telling of the actual population trends. Anderson (2001) highlights some of the problems with using indices of abundance. However, using distance sampling estimates as indices of abundance can reduce some sampling variability because the method can incorporate differences in observer detection rates (see Diefenbach et al. 2003) and model detection probability with additional covariates, such as habitat types (Marques et al. 2007) to incorporate changes over time that other estimators have trouble with.

Our results likely concluded that the distribution of deer was correlated to the distribution of the roads we surveyed, such that deer likely avoided areas near transects. Therefore, we expected the estimated detection probability (Table 1, Appendix b) was positively biased, leading to negatively biased estimates of density (estimates are likely low).

## Management Implications

Our estimate of deer density in the Blue Hills Reservation was 67 deer per square mile (Table 1, Appendix b) or 85 deer per square mile of deer habitat (85% CI = 65 – 107). Density estimates, whether lower than actual or not, were well-above DFW's deer density goal of 6-8 deer/$mi^2$ of forest for WMZ 10 and the threshold density of 18-20 deer/$mi^2$ of forest where impacts are seen in northeastern forests (Tilghman 1989, Horsley et al. 2003).

The distance sampling method does not rely on harvest data like the current DFW model; therefore, it provided an independent estimate of deer density more representative for areas with little to no hunting. The harvest-based model used statewide by DFW provided an estimate of approximately 25-35 deer per square mile of forested land for the management zone where the Blue Hills Reservation is located. Further, using only harvest data for population estimation typically provides an estimate of deer density for lands that are open to hunting. However, because the there is little to no hunting in and around the Blue Hills, density can increase without informing DFW's harvest-based model. Thus, as expected, the distance sampling estimator provided estimates much higher than the zone-wide harvest-based estimates. Areas in eastern Massachusetts with similar conditions as the Blue Hills Reservation and with little to no hunting can expect similar deer densities on their properties.

If DCR is interested in monitoring the deer population in the Blue Hills Reservation, it is recommended that distance sampling surveys are performed at least every two years to indicate trends in the population. Abundance data will be important for monitoring the population if management actions are taken.

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Appendix

**(a)** Example distance sampling datasheet for surveys conducted at the Blue Hills Reservation.

## Distance Sampling Data Sheet

**Date** ____________________
**Start Time** ___________
**End Time** ___________

**Driver** ______________
**Driver's Side Observer** ___________
**Passenger's Side Observer** ___________

**Circle Vehicle Used:**

**Truck** or **Kabota**

**Temp (Far.)** ________
**Cloud Cover (%)** 0 25 50 75 100
**Wind** ___________ mph
**Precip** None Sprinkle Drizzle Sleet Snow
**Ground** Dry Damp Wet Snow
**Visibility** 0 1 2 3 or **Miles** ______
**Comments:** ______________________________________

| | Number of Deer in Group | Park Section | Field? (check if yes) | Time | Observer (initials) | Perpendicular Distance (feet) | Intersection # or GPS Loc Other Comments: |
|---|---|---|---|---|---|---|---|
| 1 | | | | | | | |
| 2 | | | | | | | |
| 3 | | | | | | | |
| 4 | | | | | | | |
| 5 | | | | | | | |
| 6 | | | | | | | |
| 7 | | | | | | | |
| 8 | | | | | | | |
| 9 | | | | | | | |
| 10 | | | | | | | |
| 11 | | | | | | | |
| 12 | | | | | | | |
| 13 | | | | | | | |
| 14 | | | | | | | |
| 15 | | | | | | | |
| 16 | | | | | | | |
| 17 | | | | | | | |
| 18 | | | | | | | |
| 19 | | | | | | | |
| 20 | | | | | | | |
| 21 | | | | | | | |
| 22 | | | | | | | |
| 23 | | | | | | | |
| 24 | | | | | | | |
| 25 | | | | | | | |

**(b) Multiple Covariate Distance Sampling Output:**
**Forested versus open land as covariates for detection function**

```
# observations:    129

 Model
   Half-normal key
```

| Parameter | Point Estimate | Standard Error | Percent Coef. of Variation | 85% Percent Confidence Interval | |
|---|---|---|---|---|---|
| p | 0.50513 | 0.32415E-01 | 6.42 | 0.46034 | 0.55427 |
| n/L | 1.9868 | 0.28394 | 14.29 | 1.5984 | 2.4697 |
| E(S) | 1.9302 | 0.11914 | 6.17 | 1.7653 | 2.1105 |
| D | 66.812 | 11.250 | 16.84 | 52.118 | 85.649 |

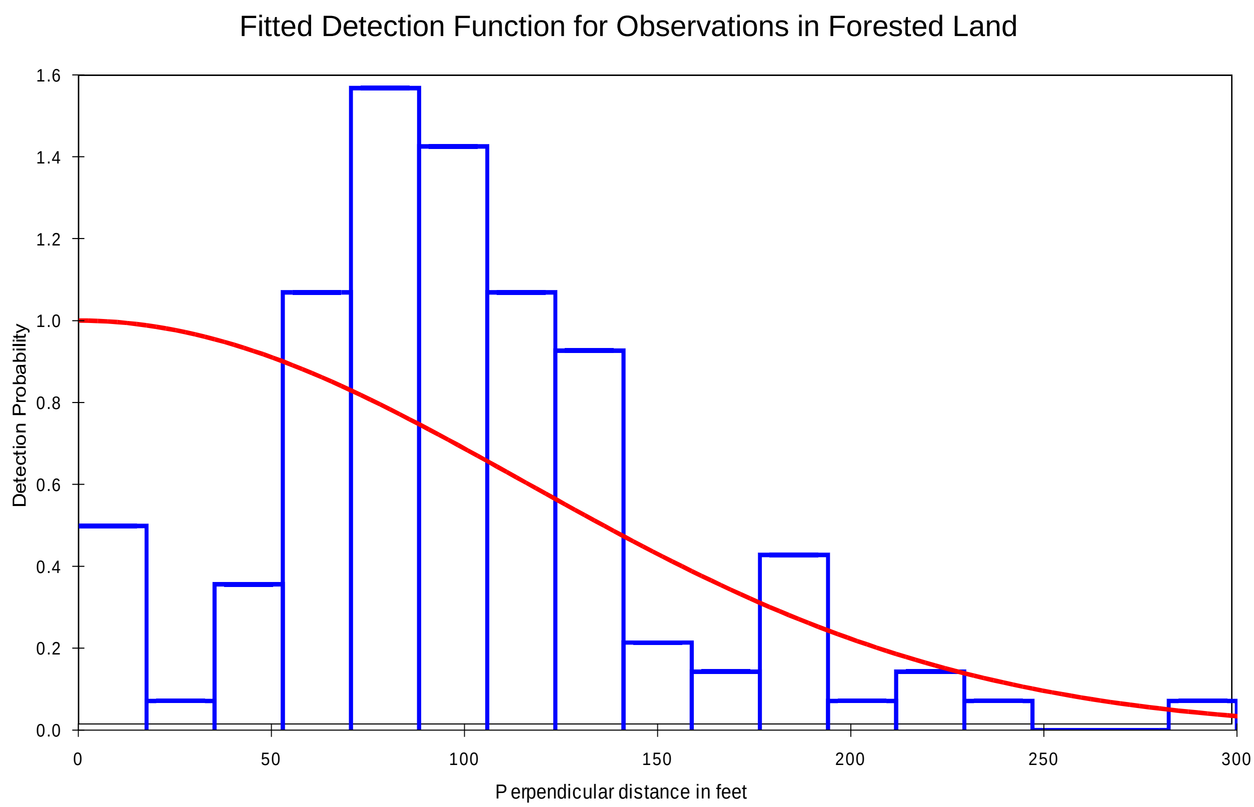
Estimate of deer per square mile was 66.8; however this area includes areas not considered deer habitat (e.g., development, roads, etc.)

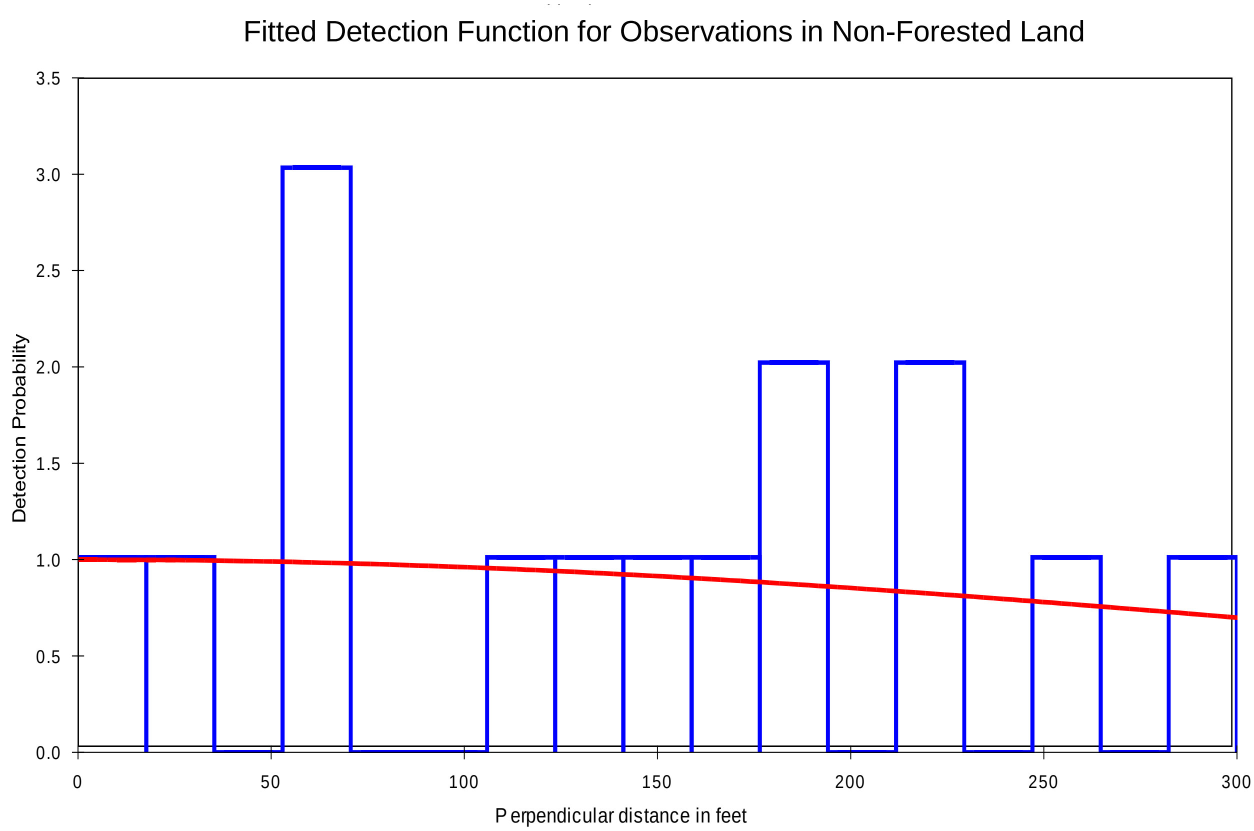
To calculate deer per square mile of deer habitat we simply divide this density estimate by the proportion of the area considered deer habitat (forested and other cover) = 80% or 0.80
**= 85 (85% CI: 65 – 107) deer per square mile of deer habitat**

```
Glossary of terms
 -----------------

 Data items:
 n     - number of observed objects (single or clusters of animals)
 L     - total length of transect line(s)
 W     - width of line transect or radius of point transect

Parameters or functions of parameters:
 p     - probability of observing an object in defined area
 E(S) - estimate of expected value of cluster size
 D     - estimate of density of animals
```


Fitted Detection Function for Observations in Forested Land
Detection Probability
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
0
50
100
150
200
250
300
P erpendicular distance in feet


Fitted Detection Function for Observations in Non-Forested Land
Detection Probability
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
0
50
100
150
200
250
300
P erpendicular distance in feet