

WildlifeDensity

Techniques Manual and User's Guide

. . . a parametric population density estimator for line transect and fixed point detection distance data

Version 2.2


School of BioSciences
The University of Melbourne
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Foreword

The origins of *WildlifeDensity* go back years: to the writerr'sl experience trying to follow bird population changes in a natural system through the year. The site chosen was then a relatively undisturbed eucalypt forest on the edge of a plateau near Melbourne, Australia, dominated by trees over 200 years old and to over 80m (260 ft) in height. The site has warm to hot summers, a dry autumn, cool winters with overnight frosts and snow that sometimes persists for days, and highest rainfall during spring. Cloud collecting at the edge of the plateau often came lower than the treetops, hiding the foliage from the ground, and producing a 'fog-drip' that increases the effective rainfall.

About 55 bird species were regularly found in this forest, dispersed throughout the vegetation from the highest treetops to the ground. Nearly all of them bred in late spring and early summer. Some then migrated in autumn, either by altitude to nearby lowlands or by latitude to northern parts of Australia, returning next spring; some followed the flowering or seeding of local trees, being abundant at those times and scarce or absent at other times; some remained in the forest all year. A notable exception is the superb lyrebird, which feeds on invertebrates in moist forest leaf litter, raking over the litter as it forages; lyrebirds nest in winter and raise their young through the spring months. Lyrebirds are found throughout the forest in winter and spring but, during late summer and autumn, when the litter dries out and large invertebrates become hard to find, they move further down the slopes to sites where the litter stays moist.

At times the forest rang with bird song, especially soon after dawn on a clear still morning in spring and often through the day; at other times, especially during winter, or when the wind rises, or during heavy rain or snow, the forest birds were much quieter. In late autumn and early winter the most conspicuous contributor to forest bird song was the lyrebird, the calls of the male being audible a kilometre or more away under favourable conditions.

Some bird species were much more conspicuous than others. A few birds of the canopy, like the sulfur-crested cockatoo, currawongs and kookaburras are highly conspicuous and easily detectable at a distance, especially when they call; so is a male lyrebird in full song on its dancing mound. Small flocks of thornbills and honeyeaters characteristically move about continually as they forage, calling frequently but also noticeable by their numbers and continual movements. Individual treecreepers, fantails and other birds of the understorey are conspicuous by their calls.

Forest birds that move about a great deal, like martins, are easily detected if the observer is in the right place at the right time; a few moments later there is no sign of them. Other, less active species of the understorey, like whistlers, are easily overlooked unless they call. Smaller passerine species of the

forest floor (like thrushes) and species of the underbrush (like scrub-wrens) are amongst the hardest to detect; inconspicuous species such as these are usually detected only when the observer is close. Small birds of the upper foliage canopy 50mor more above the observer's head, like the striated pardalote, are almost undetectable unless they call.

Methods

With a goal of monitoring such a diversity of forest bird populations through the year, which method or methods are best? Ideally such a method should make it possible to determine a species' numbers in a study area sufficiently accurately and precisely to indicate how many are present, how numbers change through the year, and how they compare with the actual numbers of other species of interest in the area, that is, compare with the *absolute* densities of those populations.

If you are familiar with bird census work and/or the relevant literature, you will know what a difficult task it can be to work out the absolute density of a bird population. General accounts such as Bibby *et al.* (2000) set out the main bird census techniques often used.

Direct counting of the number in a given space at a given moment is one option, but out of the question when vegetation occupies much of the space between observer and birds, hiding many. Another is to capture and mark all individuals of a population within a defined area in a distinctive way, then observe, map and monitor their positions intensively: this can work well but is very time-consuming and possible only for species that live fairly close to the ground. A related technique is the capture-mark-recapture method: usually confined to species that live closer to the ground, and dependent on meeting a number of rather difficult assumptions.

Nest-counting is yet another option: but feasible only in the nesting season, and then only if nesting is highly synchronised and most individuals breed. Territory mapping and various forms of 'atlassing' are good for picking up changes in a species' numbers or distribution but are essentially *relative* methods that can serve their own purposes well but didn't meet the objectives of this study.

In view of these inadequacies, a decision was made to pursue the remaining major type of survey: distance sampling. Its most familiar form, the line transect survey and, to some extent, the related fixed observing point survey, had been used successfully with grazing mammals and a variety of other species. Distance sampling requires that detection distances are recorded as well as numbers and meeting some other criteria. The well-known conventional distance sampling method used by Buckland *et al.* (2001), for example, is based on counting the numbers detected at different perpendicular distances from a transect line, and assuming that all individuals are detectable along the transect line itself; a further assumption is that the observer travels faster than the individuals in the population. The frequency distribution of numbers with distance is then modelled and that model used to derive a density estimate. Because many birds in foliage can be walked under without being seen, and many move about faster than an observer travels, another approach was necessary.

WildlifeDensity

Bird population estimation in forests and similar habitats needs a strategy that allows for factors that affect detectability, such as varying species and observer characteristics, vegetation and uneven topography in an observer's line of sight, adverse weather conditions such as mist or fog, high population mobility and the possibility that a population is well above (or below) observer eye-level.

With this in view, we developed a mainframe computer program (MNPS) to model what happens to a detection distance frequency distribution in a survey situation. It was to model frequencies of horizontal direct-line detection distances from an observer, perpendicular distances from a transect line, and be varied to model detection data from an observer at a fixed point. We restricted it to sightings rather than calls because, with most bird species, their calling behaviour proved too unpredictable to rely on for modelling. However distinctive calls *could* serve as a ready method of identification.

The density of a population is one factor that determines how many population members are detected. It affects the area under a graph of numbers at different distances. This being so, if the values of other factors affecting numbers at a distance are known for a given survey, then population density should be estimable from the frequency distribution. The model developed does not require that all individuals be detected along the transect line, nor that individuals move more slowly than the observer, but does require that data collected under different survey conditions are modelled separately and combined later where necessary. That model, rewritten and considerably refined for desktop and laptop computers, is now available as *WildlifeDensity*.

The *WildlifeDensity* approach has since been applied to a variety of passerine bird populations, to large herbivores (e.g. kangaroos) and to a variety of other animals, especially land vertebrates. It has been used in various field investigations, especially population monitoring programs for management purposes in national parks and reserves, and been validated against known populations under typical survey conditions. Finally — and importantly in this context — it made it possible to estimate the population densities of forest birds.

Grateful thanks is due to all the investigators who have worked on aspects of this approach to population estimation, many of whom are listed in Appendix D, to the government agencies that made much of this work possible, and to the hundreds of field staff who have collected field data. It is our hope that you may find it useful.

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Changes in Version 2.2

The bioggest changes in Versions 2.2 of *WildlifeDensity* involve procedural refinements to make using the program simpler and easier to use, especially with smaller sampes, and make the related changes to this *Guide*. There are also changes to the ways the models are presented.

Sadly, the Australian forest for which the *WildlifeDensity* program was originally developed was almost completely destroyed by a major bushfire in February 2009. Many people living in nearby communities lost their lives. Although the forest has regrown rapidly since then, it will take a many, many years to fully replace what was once there, if at all.

July 2018

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BACKGROUND

WildlifeDensity

The ability to estimate absolute numbers—as a density or a total population — is a frequent requirement in field studies of plant and animal populations, and a particular need in certain types of work with many bird and mammal species. Many techniques have been used. A number involve not only counting the numbers observed but also measuring the distance between the observer and the animal at the moment of detection, leading to the general term 'distance sampling' to describe them.

Line transect methods. The *line transect* is perhaps the best-known distance technique. Observers travel a known distance across an area that contains the population of interest, looking (and often listening) for animals at any distance up to the maximum possible distance at which it is possible to recognise the species. Observers typically record the numbers of animals observed, measure the detection distance to each individual or animal group detected, often the compass bearing as well and sometimes (in the case of animals above observer eye-level in trees) the angle of elevation too. Details of vegetation, topography, time of day and weather conditions may recorded too. Information is occasionally collected on population mobility as well..

An estimate of abundance is then derived. That estimate can be based either on a measured horizontal distance from observer to animals at the moment of detection (the *radial* distance) or a horizontal right-angled distance from the transect line to the animals (the *perpendicular* distance). Perpendicular distances are usually calculated trigonometrically from the radial detection distance and the lateral angle between the transect's compass bearing and that to the detection point. Aerial surveys by helicopter may use an essentially similar approach, with the observer usually at a fixed altitude above the population and using a modified way of deciding perpendicular distances.

Fixed point methods. Another distance sampling technique is the *fixed point count* (sometimes called a *point transect)*, used particularly with more mobile species such as birds. An observer is located in turn at one of a number of predetermined points within a habitat for a given time period, during which the species of interest is looked (and often listened) for. Individual animals or animal groups which, as a result of their own movement behaviour, come close enough to be detected, can then have their group size, detection distance and perhaps elevation angle and bearing recorded, together with other details of the observing situation. An estimate of abundance is then derived from these data.

***WildlifeDensity*.** *WildlifeDensity* is a computer program designed to return population density estimates from distance data collected using either line transect or fixed observing point methods, together with estimates of other properties of the observing situation. It was designed primarily for use with ground survey data on terrestrial mammal and bird populations, with species that have individuals large enough to be seen clearly with the unaided eye at distances of 10m or more. It can also be used with

data from aerial surveys using helicopters, and from certain other sampling situations as well. [It is unsuitable for use with aerial survey data collected from fixed-wing aircraft: in that situation observer visibility is restricted in complex ways.]

Conditions of use. *WildlifeDensity* has been made available as a service to research workers and field staff studying or monitoring natural populations. The program is free software, that is, the program is licensed free of charge. It has been provided in the hope that it will be useful, but without warranty of any kind, either expressed or implied, including its fitness for any particular purpose. The entire risk as to the quality and performance of the software rests with the user who, should the program prove defective, will assume any costs associated with their use of the software. Under no circumstances will the copyright holder or any other party who may redistribute the material be liable to the user for damages, including any general, special, incidental or consequential damages arising out of the use or inability to use the program (including but not limited to loss of data or data being rendered inaccurate, or any failure of the program to operate with any other programs).

The user is free to download and use one or more copies of the program without charge, either for their own use within a scientific research or monitoring program or for student use within a teaching program undertaken within a tertiary education course. *WildlifeDensity* may not be sold or incorporated within any other program which is to be sold, nor may it be modified and redistributed without the written authority of the copyright holder, and with that redistribution taking place without charge.

The Survey Situation

1

Purpose

WildlifeDensity is designed to return population density estimates from 'distance' data collected using either line transect or fixed observing point methods. (‘Distance’ data are those where the observer both counts the animals observed and measures the distance to the point where each was first detected.) The program is intended primarily for use with data collected in ground surveys of mammal or bird populations in terrestrial habitats, and also with aerial surveys using helicopters. It can be used to estimate densities from certain other species and sampling situations as well.

WildlifeDensity uses field data submitted to the program to return estimates of the overall density of the population together with estimates of other properties of the observing situation.

How the Program Works

The program uses a mathematical model to describe the frequency distribution of the animal numbers detected over a range of detection distances by an observer who either travels along a transect line or operates from a fixed observing point. The model it uses is *parametric*: certain properties of the observing situation (e.g. vegetation cover, detectability) are approximated by internal numerical constants (parameters) that can be either measured or estimated. If the observing conditions during a transect or at different fixed points vary appreciably (e.g. forest vs grassland), data sets collected under different observing conditions are modelled separately and the results combined subsequently.

For each set of field data, the program uses a curve-fitting procedure to match numerical values calculated by the model to the frequency distribution of the field data submitted to the program. This is done using the simplex method, an iterative strategy that seeks parameter values that minimise the differences between the observed and calculated numbers in each distance class across a selected range of distances. The computer run then returns its ‘best-fit’ estimates of population density and other parameters of the observing situation. Random re-sampling of the original data with replacement (’bootstrapping’) is used to estimate standard errors of the parameters. The number of resampling events is decided by the user. A total population estimate can then be made by multiplying the population density estimate by the area of habitat occupied. Where data have been subdivided by habitat type and modelled separately, an overall density estimate is then obtained by combining the separate estimates using stratification methods.

Applicability

WildlifeDensity is designed for surveys of terrestrial animals large enough to be clearly visible at a distance of 10m or more from an observer. The program is capable of making reliable and relatively precise estimates of absolute population density, given appropriately-collected data from the following survey types:

- ◆ ***Radial distance line transect surveys*** of readily-visible ground and tree-dwelling mammals and birds, especially medium-sized and larger herbivores (e.g. kangaroos, deer, possums, emus) in relatively extensive habitats such as grassland and open woodland, using measured radial detection distances from the observer;

- ◆ ***Perpendicular distance line transect surveys*** of readily-visible ground and tree-dwelling mammals and birds, especially medium-sized and larger herbivores in relatively extensive habitats, using data on perpendicular detection distances from the transect line;

- ◆ ***Fixed-point surveys*** of actively-mobile ground and arboreal bird species (e.g. songbirds) in both extensive and localised habitats, using measured detection distances; and

- ◆ ***Aerial surveys*** of larger ground-dwelling herbivores in grassland and woodland habitats where there is a relatively unrestricted view of the ground, by observers working from helicopters operating at a set height and following a line transect protocol, and where the aircraft is fitted with sighting equipment capable of assisting in the collection of usable perpendicular distance data.

- ◆ ***Other surveys.*** This method of density estimation can work with data collected not only in daylight but also in nocturnal spotlight surveys, and has also been used successfully in certain other situations (e.g. in estimating the densities of surfacing fish schools using fixed-wing aerial surveys over the open ocean).

The technique is best-suited to populations distributed across fairly extensive terrestrial habitats; *WildlifeDensity* has proved less useful in analysing line transect data from highly fragmented terrestrial habitats (e.g. ponds and watercourses). It is not recommended for use with mammal and bird species that are very small, or highly gregarious, or live in extremely dense cover, or are very wary and hide from an approaching observer (e.g. felids). With fixed-point surveys, the usefulness of *WildlifeDensity* depends on the target species being actively mobile (making possible sufficient detections) and on there being separately-collected data available on their overall movement rates.

Modelling the Survey Situation

Because *WildlifeDensity* depends on using some mathematical models, it is important to understand the nature of a mathematical model and something of its advantages and limitations.

Models. A dictionary defines a model as 'a miniature representation of a thing', or 'something intended to serve, or that may serve, as a pattern'. A child's toy car or doll is a model: it is a miniature, simplified representation of the real thing. The toy car usually lacks an engine and many other components of a full-sized car; a doll similarly is a simplification. However both models have sufficient attributes of the real thing to serve their purpose: to reproduce those characteristics of a car or doll that interest a child of a particular age, and suit his or her needs at that stage of development.

A mathematical model of a line transect or fixed point sampling situation can also be a simplified representation of 'real-world' circumstances. It need not fully represent all attributes of the real situation provided that it serves its purpose: to pattern the real situation well enough to produce density estimates sufficiently accurately and precisely to serve the investigator's needs.

Mathematical models are, fundamentally, sets of symbols and logical operations based on a set of *assumptions* that underlie the model. [Former mathematics students may remember proofs based on reasoning such as: '*Let, or If'* (an assumption) be the case . . . *then it follows that* (certain logical consequences occur).] It is possible to use mathematical models to represent what happens in a line transect or fixed observer count (*i.e.* the survey situation) by using the symbols, numbers and some of the standard logical operations of mathematics, and then using that model to obtain a density estimate for the population. This approach can be a valid *provided that the assumptions of the model were met in the field* when observers collected the data. If the model has been appropriately-designed and its key assumptions met, the density estimate should then be dependable.

There are two types of mathematical model used by field workers to estimate population densities. ***Parametric models*** attempt to represent the characteristics of the observing situation by means of a set of constants (parameters) within the model; *WildlifeDensity* is based on parametric models. ***Non-parametric and semi-parametric models*** do not attempt to represent characteristics of the observing situation within the model; the well-known density estimator *Distance* is an example. Both types of model depend on specific assumptions: for example, a well-known assumption of the *Distance* approach is that all individual animals along a transect line itself are either detectable or the observer knows the proportion missed. To use *WildlifeDensity* correctly, there are also key assumptions to be known and met.

Animal detectability and distance. In survey work with terrestrial animals, especially larger mammals and birds, there is always a decline in visual detectability (sightability) with increasing distance from an observer. The further an animal is from the observer, the more likely it is to be overlooked. There are two main reasons: the first is that there is a greater chance of an individual animal being hidden behind objects (vegetation and topography) as distance from the observer increases; the second is that a more distant animal produces a smaller image on the observer's retina that is less likely to be discriminated from all the other images in their field of view.

Mathematical modelling of the observing situation can be a particularly useful tool for describing, interpreting and predicting what happens during such surveys. For example, the fall in detectability with distance can be described mathematically as a decline in the probability of detection. A deer or kangaroo immediately in front of an observer on the ground is always detected (*probability=1*); at greater distances the probability is progressively less than 1 ($1>p>0$); ultimately a distance is reached beyond which recognition is no longer possible ($p=0$) — *see Figure 1 on the next page.*

From various studies we know that the number of individual animals detected at a particular distance from an observer depends on the overall population density, on any factor which affects the probability of detection (*e.g.* the type of animal, habitat characteristics), and on the number of animals already detected at greater distances and now disregarded by the observer. This situation results in a frequency distribution of numbers with distance that has a distinctive shape characteristic of the particular distance being measured: horizontal radial or perpendicular.

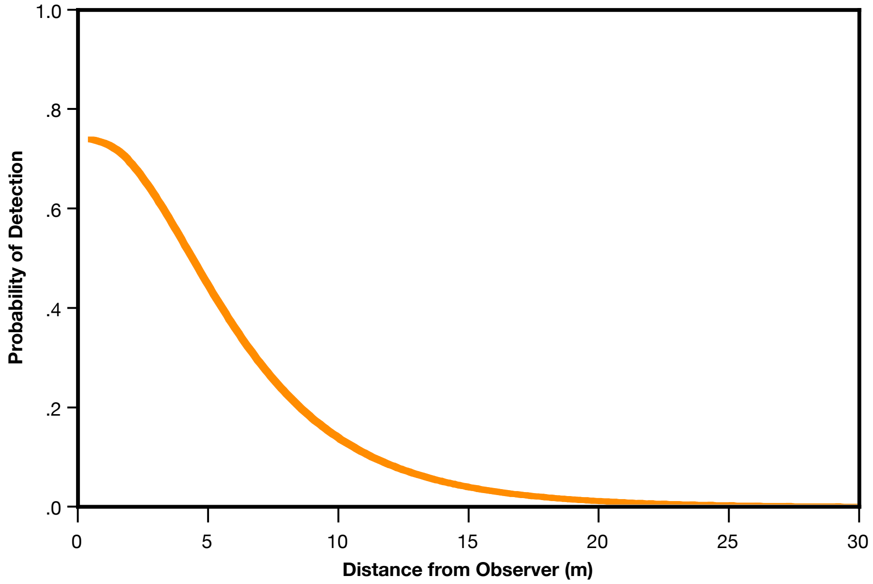


Figure 1. The way in which the probability (p) of detecting a typical songbird within foliage ahead varies with horizontal distance. There is a change from a high probability of detection *(p approaching 1)* near the observer to a negligible possibility of detection at 30m ahead (*p*=*0*).

The line transect situation. Consider the typical line transect situation, in which an observer walks through a given habitat containing a population of animals (e.g. deer, kangaroos) scattered about in more or less the same horizontal plane as the observer. As the observer moves forward, individual animals or groups of animals are detected or flushed and so are detected ahead of the observer from time to time. Such a line transect situation is shown in Figure 2 (*next page*).

Horizontal distances to each animal at the moment of detection are measured from the observer (the so-called ‘radial distance’ *r*) and/or from the transect line (the so-called ‘perpendicular distance’ *y*). A lateral observing angle (ϕ) may also be measured. Such data are accumulated by an observer in a data record, together with group sizes and other data.

When radial distance data from a particular terrestrial line transect situation are arranged as a frequency distribution, the full distribution has a characteristic shape when plotted as a graph. Look at the example shown in Figure 3 (*next page*). There are usually no observations at very short distances from the observer. Then, as distances become greater, the number of detections at each distance rapidly rises to a peak, after which the number progressively falls to zero at some maximum detection distance from the observer.

In contrast, when perpendicular distance data from a particular terrestrial line transect situation are arranged as a frequency distribution, the full distribution also has a characteristic shape, but a different one. Figure 4 (*next page*) shows a typical perpendicular distance frequency distribution. The numbers detected are usually greatest close to the transect line, then decline progressively in a reverse sigmoid (S-shaped) fashion to zero at some maximum distance from the transect line (usually the same maximum distance as for radial distance data).

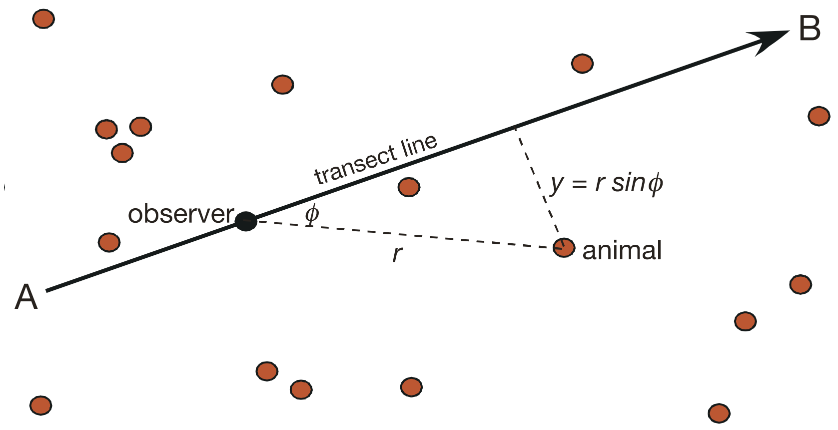


Figure 2. The typical line transect observing situation on the ground, with the observer within the plane of a population of animals *(red dots).* The observer walks a line transect from Point A to Point B, looking for animals ahead. Once detected, an animal's radial distance *r* from the observer and often its angle of detection (φ) from the transect line may be measured. Using this angle, the animal's perpendicular distance *y* from the transect line can be calculated using trigonometry.

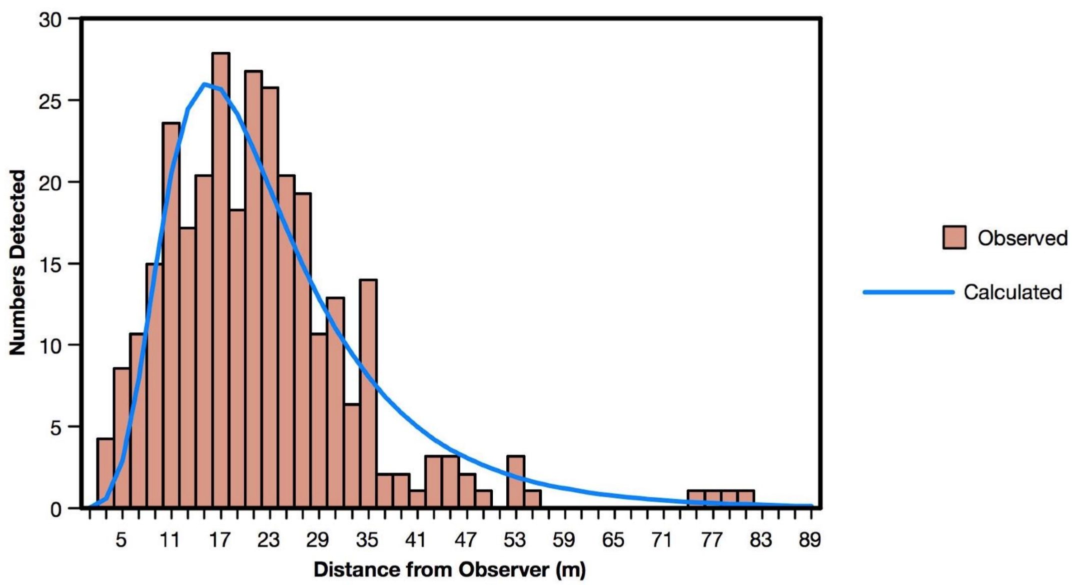


Figure 3. A frequency distribution of horizontal, radial detection distances from observer to animal at the moment of detection. The data *(brown)* are a sample of 300 honeyeater detections in the canopy of an Australian eucalypt woodland. The blue dotted line is that returned by modelling these data using *WildlifeDensity*. The shape of this frequency distribution is characteristic of both line transect radial distance and fixed point distributions: a bell-shaped distribution skewed to the right. *(Data: S.J.Headey)*

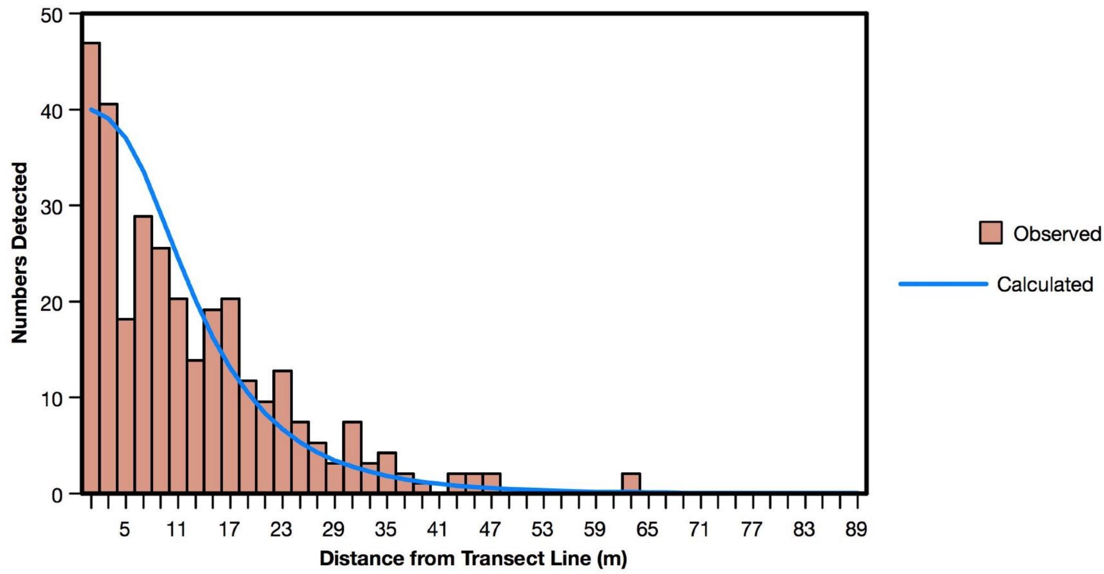


Figure 4. A typical frequency distribution of perpendicular distances measured in a horizontal plane from a transect line to the animals' positions at the moment of detection, together with the model produced by *WildlifeDensity (in blue).* Data are from the same data set as Figure 3. Detection frequencies fall away from their highest value near the transect line to zero at about 85m distance. Often such distributions show a 'plateau' (flat portion) close to the transect line and have a somewhat sigmoidal (S-shaped) form, reversed. *(Data: S.J.Headey)*

Whether radial or perpendicular distance data are collected, and there are sufficient observations, the general form of each distribution type is constant and recognisable. However the *precise* shape of the curve differs from one set of data to another. The height of the curve and the area underneath it, the distance at which the peak of the curve occurs (in the case of radial data), the slope of the curve at any particular distance, and the maximum detection distance can differ from data set to data set. Part of this variation is due to random, stochastic events and part to observer measurement error; however much of it can be shown to be due to certain attributes of the particular sampling situation itself.

Fixed point counts. In the type of fixed point count modelled by *WildlifeDensity,* an observer is located inconspicuously at a point in a habitat where there is a mobile population of a species of interest (e.g. a passerine (song) bird). The observer remains at that point for a predetermined period of time, rotates slowly and, as they do so, watches for individuals and groups to become visible as they move about normally. Group size, horizontal detection distance and perhaps elevation are recorded at the moment of detection; an individual or group's position after that is then monitored. If an individual or group moves away and then is subsequently re-contacted, that re-contact is treated as a new record.

The fixed point observing situation is as if an observer is surrounded by a series of concentric observing circles, each of radius r (the horizontal detection distance), each centred on the observer (*see Figure 5*.) Animals are moving about at a variety of speeds and directions, being recorded at a horizontal detection distance r once they are close enough to be seen. Any animal closer than the maximum possible recognition distance is potentially detectable. An individual animal or moving group is effectively detected as it crosses the perimeter of one of these invisible circles; the observer then measures the horizontal distance to the detection point.

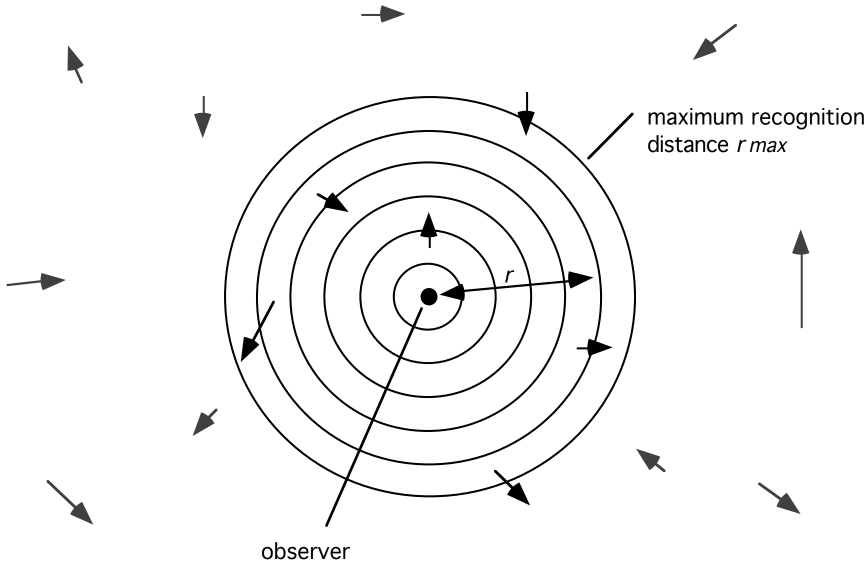


Figure 5. A fixed point survey situation, with an observer surrounded by a series of concentric observing circles of radius *r*, centred on the observer. Individual animals are moving at a variety of speeds and directions. They are contacted when they come close enough to the observer to be detected as they cross the perimeter of one of these observing circles.

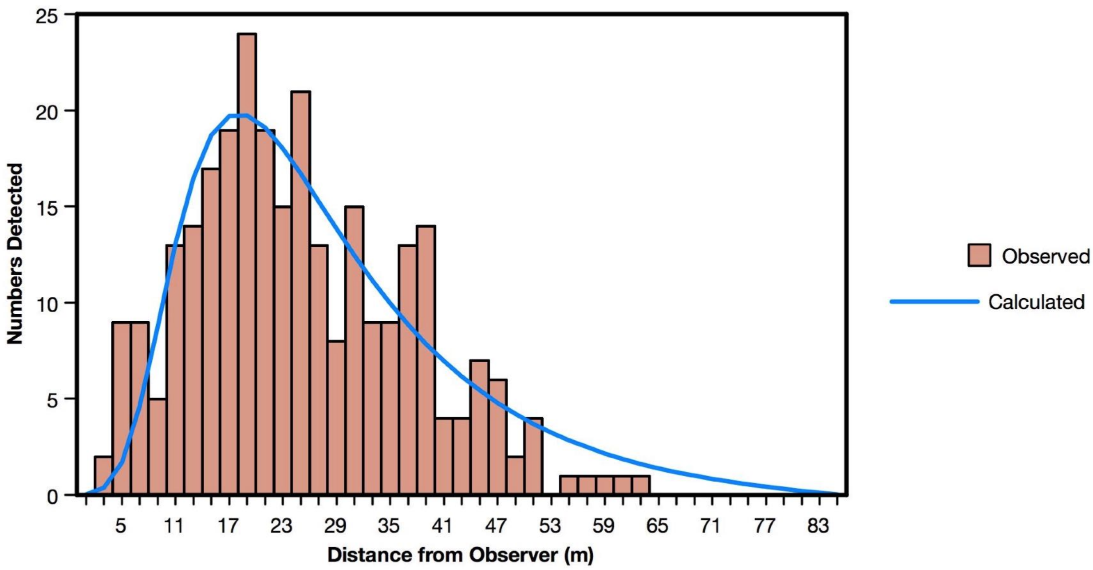


Figure 6. A typical frequency distribution of measured and modelled fixed point survey horizontal distances from observer to animals at the moment of detection, based on 273 detections of the same species and in the same habitat as Figures 3 and 4. The overall form of the distribution is very similar to that of radial distance data *(see Figure 3)*. *(Data: S.J.Headey)*

The distributions of fixed observing point distances are very similar to those of radial distance data (*see Figure 6).*

Factors that affect the shape of a frequency distribution. Assume that observing conditions during a distance sampling survey are usually fairly constant. The numbers detected at a given distance from an observer (or a transect line) and the overall shape of its frequency distribution can be shown to alter if any of the following change:

- *characteristics of the species* (size, colour, pattern, shape, group size, behaviour — *see Figure 7*);
- *characteristics of the surroundings* (vegetation cover, topography, weather conditions — *see Figures 8a and 8b*);
- *observer characteristics and behaviour* (eyesight, scanning behaviour, identification skills, alertness level, attention to task — *see Figure 9*);
- *vertical distance* between the observer and the plane of the population (e.g. an animal population in trees above a ground observer, or on the ground surface below an aircraft — *see Figure 11)*, and . . .

for line transect surveys from any kind of vehicle (car, truck, aircraft):

- *vehicle speed* (which affects the time available to count; and
- *visibility restrictions* to the observer's field of view imposed by the framework of the vehicle.

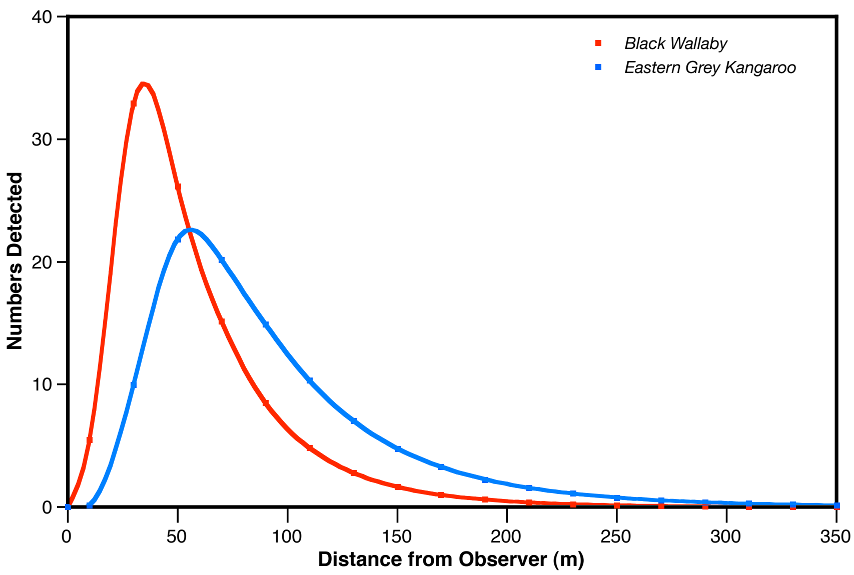


Figure 7. The effect of species characteristics on the shapes of radial distance frequency distributions of line transect data from the same forest type. The modelled distribution of a 1.2m tall herbivore, the eastern grey kangaroo, is shown ***in blue***, while that of the much smaller 0.8m black wallaby is shown ***in red***. Numbers detected are expressed as percentages of all detections of that species. The two distributions are similar in shape but differ in the positions of their maximum values and their slopes at any given detection distance. The larger, more conspicuous kangaroo tends to be detected at greater distances.

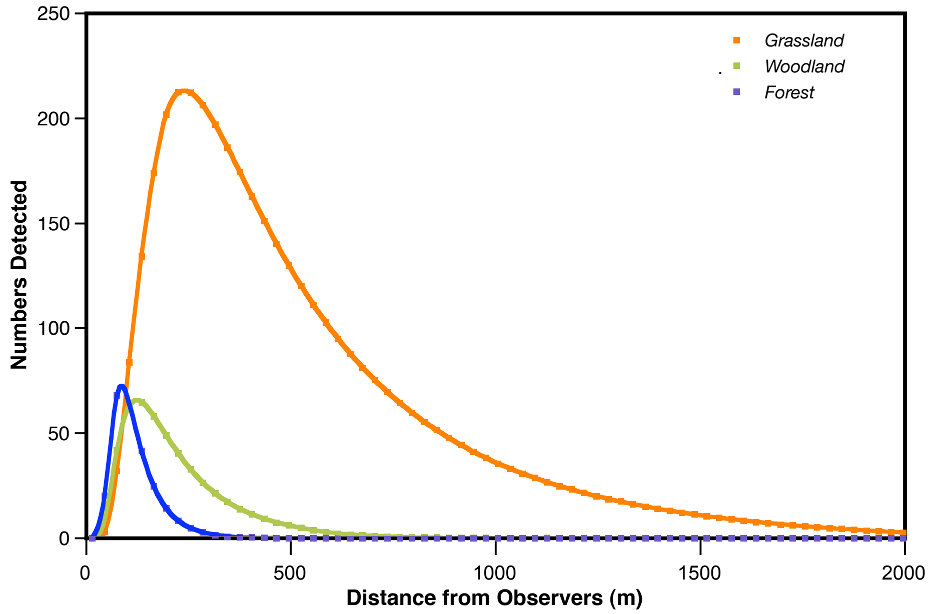


Figure 8a. The effect of a habitat characteristic (vegetation cover) on the modelled frequency distribution of line transect data from the same species (eastern grey kangaroo) in three different vegetation types in the same general locality (***orange*****:** grassland; ***green:*** woodland; ***blue*****:** forest). Vegetation cover can have a considerable impact: increasing the amount of vegetation cover between observer and animals reduces both the total numbers detected and the distances at which they are detected. Weather effects (*e.g.* mist, fog) are similar but usually less pronounced.

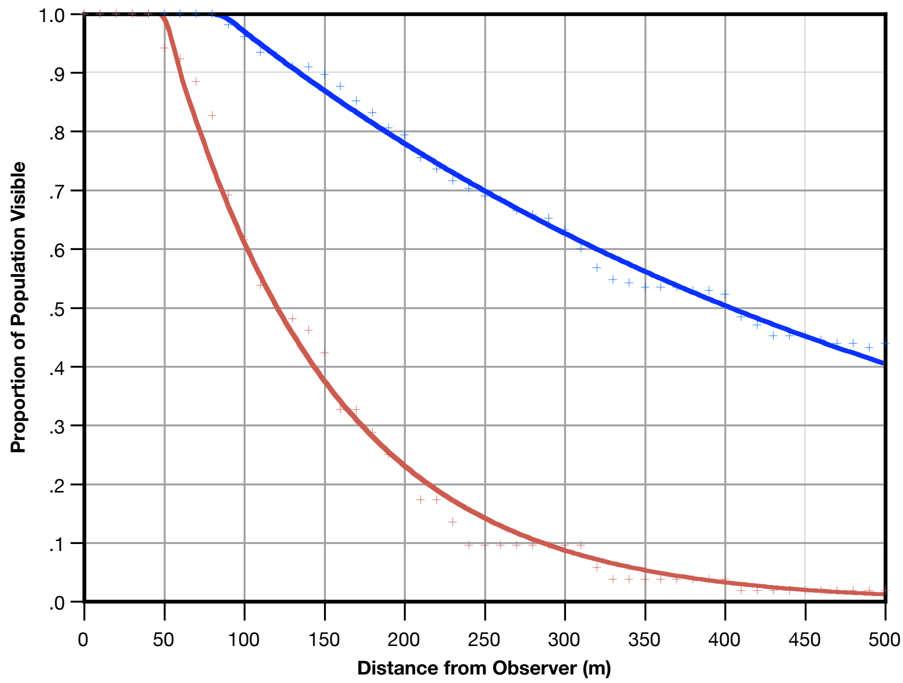


Figure 8b. This graph shows the proportion of a population visible at increasing distances from an observer where ***(in blue)*** topography is gently undulating and where ***(in red)*** there are higher, steeper hills *(*without vegetation in either case). The effect of topography on detectability is different in one respect from that of vegetation cover or weather. Topography has no effect for some distance from the observer (86m in the first case, 49m in the second) then, at greater distances, there is a progressively greater drop-off as more and more animals are hidden behind

topographical features (hill and ridge crests) as the distance increases — much like the effect of vegetation on detectability. The hillier the landscape, the greater is the effect. On level ground, or at distances less than the 'trigger' distance, topography has no effect on detectability.

These factors affect both the numbers detected at increasing detection distances and the shape of the frequency distribution. The variables that represent these factors in the model (*e.g.* conspicuousness, cover) can therefore be described as *shape parameters*, a 'parameter' being a mathematical term that defines the attributes or sets the conditions of a system. They are properties of the observing situation that determine the effects of distance on detectability, expressed in a numerical form.

Factors that affect the height of the frequency curve. In addition to the shape parameters, there are several attributes of the line transect or fixed point situation that affect the total number of detections but have little or no effect on the shape of the frequency distribution. Increasing any of these simply increases the numbers at all detection distances to a similar extent. The height of the frequency distribution curve alters but not its shape.

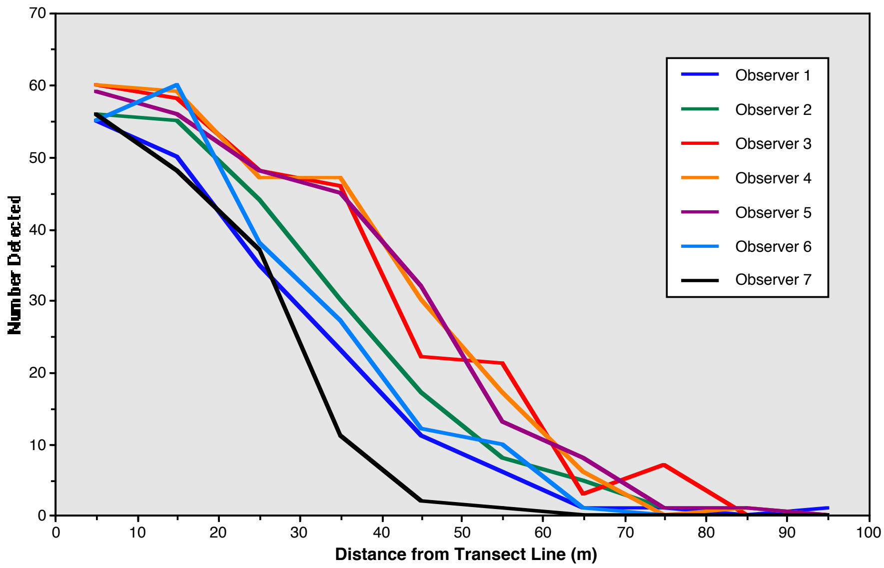


Figure 9. The effect of the observer on the frequency distributions of perpendicular distance data on a simulated animal population (numbered tags on tree-trunks) during identical, replicate line transect surveys by 7 observers in a eucalypt forest near Melbourne, Australia. All these distributions have the typical overall shape of a perpendicular distance frequency distribution, with the maximum frequencies close to the transect line and a reverse sigmoid-shaped decline to zero at greater distances. However there are considerable differences between observers in the numbers observed at particular detection distances: compare the frequency distributions from Observers 3 and 7, for example. The shapes of radial distance frequency distributions of data from these observers differed in similar ways. However the density estimates obtained by modelling all but one of the observers' data, and their data combined, proved to be similar, acceptably accurate and precise. *(Data: J.Wischusen)*

These *other parameters* are the:

- ***absolute density*** of the population (the higher the density, the more detections

there are);

- *transect length* (the longer the transect, the more detections there are);

- *relative movement speeds* of animals and observer (the faster animals move relative to the observer's rate of travel, the more detections there are);

- *sampling practices,* such as the number of sides of a line transect line being watched, or the proportion of an observing circle surveyed from a fixed point; and

- *proportion of the population potentially visible* (e.g. not in burrows, tree hollows or sheltered nests).

When any one of these parameters is altered, only the area under the frequency distribution curve is affected, not its shape.

Because all the above parameters affect detectability, and many of them vary from place to place and time to time, detectability tends to vary from one observing situation to the next. However the shape of the frequency distribution of detection distances is recognisably similar across different samples when the parameter values are similar (*e.g.* different line transect samples of the same species from the same type of woodland under similar conditions). Furthermore, population density is one of the factors that determines the numbers detected and in turn the height of a frequency distribution curve. It follows that modelling the frequency distribution of detection distances mathematically is a potentially rewarding way of estimating population densities. If the other parameters of the sampling situation can be known or approximated, for example, then density can be estimated from the model.

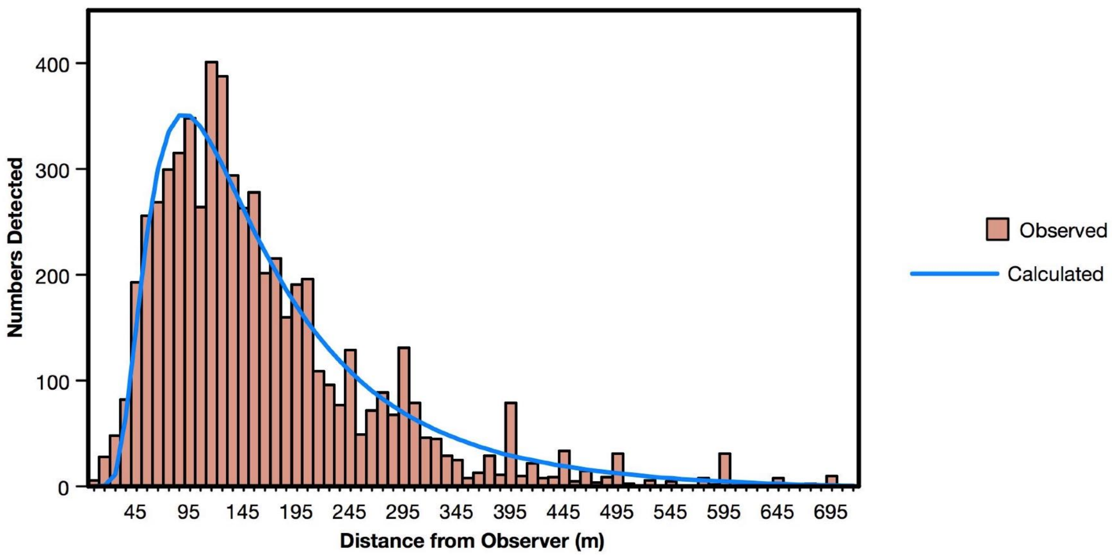


Figure 10. The fit of the *WildlifeDensity* model to a large sample: 2811 radial distance detections (6136 individuals) of a species population in a particular habitat — western grey kangaroos in an Australian eucalypt woodland. The distribution is closely approximated by the model *(blue line)*.

Modelling the frequency distributions of detection distances. Because absolute population density is one of the factors that determines the height of a frequency distribution curve, it is theoretically possible to model the distribution, then estimate its population density when values of the other factors can be known or approximated. Such models are of the two types introduced earlier. *Parametric models* are mathematical equations that try to represent the characteristics of the observing situation by means of a set of constants (parameters) within the equation. *Non-parametric and semi-parametric models* try to model the shape of the distribution without attempting to characterise the observing situation; instead, they rely on fitting standard mathematical distributions that have similar shapes to field survey data. Both types of model work by using a suitably-designed computer program to fit the model to field data, then use the model to estimate the population density.

WildlifeDensity takes the parametric approach. Considerable effort has been put into modelling the shapes of the line transect and fixed point frequency distributions well enough to estimate a population density from a set of line transect data. Three different but essentially similar models resulted. They represent radial distance distributions, perpendicular distance distributions and fixed observing point distributions respectively. Each model provides an approximate representation of relevant data. Mathematically-inclined users interested in the structure of these models are referred to Appendix A of this Guide.

Key assumptions in *WildlifeDensity* models. Before writing any model, a researcher has to begin with a set of assumptions about the system he or she is going to describe mathematically, then use those assumptions to build the model. If data are subsequently to 'work' with that model, they should then also have been collected in an appropriate way in situations to which those assumptions apply. What those assumptions are therefore thus needs to be clear. Some assumptions depend on the way the observing team carries out its task while others are outside a team's control. Some assumptions differ between types of survey, while others remain the same whatever the particular method used. The main assumptions are as follows:

A. All techniques:

(1) Survey design. Transects and sampling points are (a) placed within the area of interest independently of the way the population is dispersed in the area, in such a way that (b) all parts of the area are equally likely to be sampled.

(2) Species recognition. The observer can (a) discriminate the animal from its background by sight, sound or in some other way (usually by sight) and (b) identify it correctly once it is within some (threshold) maximum recognition distance from the observer.

(3) Habitat characteristics and detectability. There is a medium (*e.g.* vegetation cover) between an observer and animals in the population which (a) reduces their chance of detection as distance increases in such a way that, the further they are away from the observer, the lower is their probability of detection until (b) an effective maximum detection distance is reached beyond which they are effectively either undetectable or unrecognisable. The probability of detection may change when habitat characteristics or other observing conditions change.

(4) Observing conditions. Observing conditions (e.g. weather, vegetation cover) are monitored during a survey and recorded in such a way that: (a) the data set can be subdivided readily into sampling units (transect sections or periods at a fixed point) that differ greatly in detectability (e.g. in

vegetation cover) though, in each, observing conditions remain fairly uniform (or uniformly heterogeneous) over a sampling period; and (b) those sets of conditions are given suitable names (e.g. open grassland, grassy woodland) so that data collected under similar conditions at other times can be collated readily.

(5) *Independence of observer position.* At the moment of detection, individual animals are dispersed in a fairly horizontal plane within the sampled habitat more or less independently of the position of the observer, *i.e.* they have not responded to the presence of an observer by either moving away or being attracted by his or her presence or approach *before being detected*.

(6) *Vertical population dispersion.* The population is dispersed within its habitat in an approximately horizontal plane about some central level in such a way that most horizontal detection distances from the observer or transect line are greater than the depth of the plane — *see Figure 11*. This happens provided that observer eyelevel is not too far above or below the population level; otherwise modelling their distribution effectively becomes very difficult.

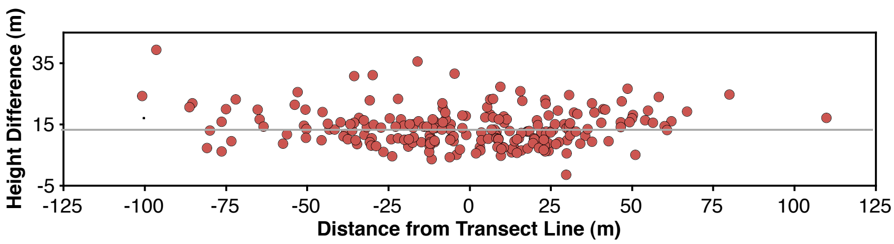


Figure 11. The distribution of koalas around a line transect in eucalypt woodland in undulating terrain in south-eastern Australia. Koalas were detected on both sides of the transect line, at heights from 3m below observer eye-level to over 35m above it. Their dispersion pattern within the vegetation canopy is roughly in the form of a plane centred around the horizontal line (the root mean square height difference). Most horizontal detection distances exceed the depth of the plane because the observers were not far below the population.

(7) *Animal movement patterns*. For mobile animal populations with an overall movement rate equal to or greater than that of an observer (e.g. most birds), (a) the animals' average movement rate (in horizontal distance travelled per unit time) is known and (b) individual animals move about before detection in directions that are approximately random with respect to the path of the observer (such that, given a uniform habitat, movements in any given direction would be equally likely).

(8) *Proportion detectable.* A known proportion (P_d) of the population is active and potentially detectable over the period of observation. (The value of P_d will commonly be 1, except in situations where some of the population — e.g. rabbits in burrows, passerine birds hidden in nests — is out of sight, when P_d will be less than 1.)

(9) *Making observations.* During the survey itself, observer(s) scan the habitat(s) around them systematically and continuously, in such a way that (a) sightings in any direction are equally likely, (b) the point at which an animal or group first becomes detectable is identified and the horizontal distance to it measured (even if the animals are disturbed and then move away), (c) the number of individuals visible to the naked eye is counted accurately (any additional individuals detected later being considered as members of a 'new' group at a new distance), (d) all instrumentation used to measure distances, bearings or elevations is accurate, and observers have learnt to use it correctly,

(e) bearings and angles of elevation to detection points are also measured when relevant, (f) habitat conditions are monitored continually, (g) the survey is subdivided into sections within which observing conditions (e.g. vegetation type) are fairly uniform, (h) starting and finishing times of each section are noted, (i) all data are recorded at the times they are made on a suitably-designed record sheet, and (j) disregarding any animals clearly visible from the starting point of a transect (because the detection distance measured will be too short), and ceasing a transect short of any animal barrier (e.g. a fence) that may limit the detection distance ahead.

(10) Number of detections. You make enough detections during the survey to get a fairly precise estimate of density. If you use radial distance measurements to estimate density, and the animals are in clusters, you may need 100 or more detections, and more if you rely on perpendicular distance data. If animals are seen singly. as few as 20 detections may be sufficient. In general, the more observations you make, the better.

B. Line Transects only

(1) Animals behind the observer. Animals detected behind the observer (*i.e.* behind a line drawn through the observer's position at right angles to the transect line) are not included in the count unless they overtake the observer from behind (in which case they are counted only without the detection distance being measured).

(2) Observer behaviour. Observers (a) move quietly and as inconspicuously as possible, pause when animals are disturbed, (b) travel sufficiently slowly to avoid missing animals flushed, and (c) endeavour to maintain a steady rate of travel.

C. Fixed Point Counts only

(1) Location. The observer has moved quietly and inconspicuously to a predetermined observation point within an identifiable, fairly uniform habitat type and has waited for a time to allow for any population disturbance.

(2) Rotation. The observer rotates continuously (and looks up and down also, as appropriate), so that (a) observations in any compass direction and elevation are equally possible, and (b) the observer's rotation covers the full 360° circle or, if the arc swept out is less than 360°, the number of degrees of arc swept out is known and recorded.

(*3) Making observations.* (a) Observations are made over a known period of time (usually measured in minutes). (b) An individual animal or animal group is treated as 'observed' when — as a result of its own independent movements — it is sighted and recognised (not heard without being seen). It is then kept under observation (and regarded as still present) until — again as a result of its own movements — it is lost to the observer's sight. (c) Any further sightings are treated as new observations (regardless of whether each is of an individual not previously sighted or is one already sighted, lost to view and subsequently re-sighted).

Ways of ensuring that the various assumptions of *WildlifeDensity* are met during field work are considered in the next chapter.

PART TWO :

FIELD TECHNIQUES

Field Equipment

2

Population estimates need to be reliable. Whether or not you can rely on the results from any population estimation technique depends very much on how well the data were originally collected. First, field procedures must meet that technique's basic assumptions. Secondly, care and thoroughness are essential.

This chapter is the first of four on field techniques, based on years of experience by field workers. They present ways of collecting field data we have found can help you achieve trustworthy estimates. This first chapter focuses on data recording and field equipment. It begins by setting out the basic information required from a line transect or fixed point survey, lists the equipment needed and provides some information on how to get the most from rangefinders and magnetic compasses. Field procedures for the survey techniques are considered in Chapter 3 (Line Transect Sampling), Chapter 4 (Fixed Point Sampling) and Chapter 5 (Animal Mobility and Topography).

Data Records

Whether a survey involves line transects or fixed observing points, you need certain information to ensure that the data are identifiable, locatable in space and time and sufficiently well described that others could repeat your procedure if they wish. The following basic information is usually needed, recorded at the time, and on a well-designed data sheet *(see later)*. Other required data are set out under the relevant survey type (transect or fixed point) in Chapters 3 and 4.

Survey/sample identifier. Every set of survey data needs a distinctive name or code number to identify it and distinguish it clearly from other surveys. One convenient form of identifier abbreviates the locality and sampling date (e.g.KNP24Aug10).

Survey locality. Information on the general area where the fieldwork took place is also needed, in sufficient detail so others can locate it fairly precisely. Sometimes a distinctive name is sufficient, at other times the relevant latitude and longitude, at other times again appropriate map references.

Sample locations. Each sampling location needs to be identifiable within the overall study area. With line transects, the start and end points should be recorded in sufficient detail, for example by a clear description or their Universal Map Grid (UMG) grid references, together with the compass bearing of the transect (if it follows a straight line). With fixed point samples, a grid reference or site description is usually sufficient. In addition, a map of the sampled area with either the transects or sampling points marked is usually helpful.

Sample durations. The length of a transect or transect section (in metres or kilometres) and the time spent (in minutes) are also needed while, for fixed points, just the time spent (in minutes). Transect lengths can be worked out from a map after a transect has been completed; start and finish times should be recorded at the time. Time durations for fixed point counts should be decided beforehand.

Units. Calculations in *WildlifeDensity* assume that all distances are measured using the S.I. (metric) system. If original data are measured in other units (*e.g.* feet, yards, miles), convert them to metric units before submission to the computer. Always measure; never estimate or guess a measurement.

(1 ft = 0.3048 metre; 1 yard = 0.9144 m; 1 mile = 1.609 km = 1609 m)

Target species' names and abbreviations. Your data record should state the name(s) of the targeted species, and at least two or three-letter species' name abbreviations for your field data records (*e.g.* KL for koala, MD for mule deer, PFN for peregrine falcon).

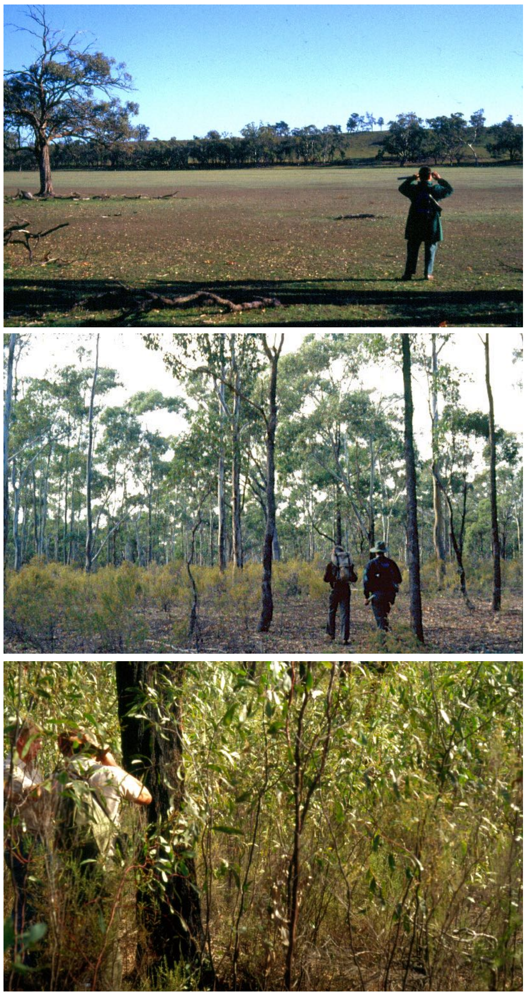


Figure 12. Three vegetation types that differ in animal detectability: open grassland *(top)*, open forest *(centre)* and dense scrub *(bottom)*. For a (hypothetical) population with an equal density in all three habitats, and transects of equal length, most individuals will be seen in the open habitat and at the greatest distances, while fewest will be seen in the scrub, at the shortest distances. Data from such disparate habitats needs to be identified clearly in the records for separate analysis later.

Topography. Sufficient description of local topography to indicate at least whether the sampled site is level, undulating, or hilly. Additional information, *such as* a contour map of the site, may also be helpful *(see below)*.

Vegetation types. Many wildlife surveys take place in more than one identifiable vegetation association (natural community) — see Figure 12. Different habitats can differ greatly in the average amount of cover in a line of sight between an observer and the animals in a population, and the amount of lateral cover can have a major effect on detectability. Also, a population's density distribution across a landscape is often relatable to habitat characteristics. An important early task in any population survey is therefore to classify vegetation into habitats with different visibility. After the survey you collate (sort) the data by habitat type, then analyse it separately and obtain a density estimate for each major habitat type using *WildlifeDensity*. To obtain a pooled density estimate, you then combine the density estimates from the different habitat types, weighting each habitat's density estimate by the proportion of the survey area it covers (*see later*).

A simple habitat subdivision based on the structure of vegetation (e.g. forest, woodland, grassland) is usually sufficient for a density estimation, though additional information (e.g. on its plant species composition) may be useful for other purposes. If other observers assist with a survey, it may help to equip them in the field with laminated photographs of the principal vegetation types. This can ensure that all observers use the same classification system.

With fixed point counts, it can help if you locate each sampling point clearly within one of the identified vegetation types. If a selected sampling point is on a site transitional between habitats, move it a short distance until it lies distinctly within the nearer clearly-identifiable vegetation type.

Date(s). The date(s) on which the data have been collected (e.g. 24 April 2016).

Personnel. The first and last names of those who collected the data, and the roles that each played during the survey (e.g. observer: James Brown; recorder/navigator: Mary Black).

Weather conditions. Certain weather conditions may affect detection distances and the numbers seen, especially precipitation (rain, sleet, snow), strong winds, and (at times) lighting conditions and extremes of temperature. Record a general description of weather during a transect or fixed point sampling period as a mater of course. This can usually be done adequately by most field workers with a little practice (e.g.: 'overcast; intermittent very light rain; mostly calm, with an occasional light breeze; 15-20°C'). However if weather conditions are making a survey difficult it is usually better to stop collecting survey data; consider choosing another day.

Detection distance data. Finally, the main items in the data record are the counts of population group sizes and the measurements of their detection distances and sighting angles. Well-designed data recording sheets on a clipboard can make data-recording both easier and more consistent. An example is shown in Figure 16 in Chapter 3. We suggest you avoid electronic data recording unless you can <u>see</u> what you record; avoid any method that lets you make errors without noticing them.

Equipment Needs

Whether a line transect or fixed point, an individual or observing team needs several pieces of equipment.:

- *Rangefinder* — to reliably measure the expected range of detection distances. The laser type is preferable,; it should be tested and calibrated if necessary before use, provided with a battery and

a spare, and have clean lenses. (Some information on rangefinders and how to use them is set out below.)

◆ *Inclinometer* — to measure angles of elevation if animal detections are expected well above observer eyelevel (otherwise not required).

◆ *Wrist watch or other timepiece (e.g. smartphone)* — to monitor time, accurate to at least the nearest minute.

◆ *Magnetic compass* — for navigation and to measure bearings if detection angles are required, of a type that is both accurate and easy to use (*see below*). Knowing the magnetic deviation in the study area can help field workers relate compass bearings to maps of the area. (GPS units and some smartphones can also be used for this if suitable units are available.)

◆ *Binoculars* — for use in species identification only, not as a routine aid to detection *(see Ch.3).*

◆ *Data sheets* — designed to suit the technique used and pre-printed, with some way of dealing with rain (*e.g.* within a clipboard with a clear plastic cover, or on sheets of waterproof material). A notebook can also be used, though using one often leads to omissions from the data.

◆ *Pencils or waterproof pens* — for data recording, in working condition, and with a spare or a sharpener as well.

◆ *Survey information* — locality details, species identification information, survey procedures to be followed.

◆ *Maps* — to show the locality in which the survey is being taken and assist in navigation, preferably laminated if rain is possible.

◆ *Clipboard* — to hold and support field data sheets, maps, survey information and field identification notes as necessary — of a type that can be closed or covered in the event of rain.

◆ *Personal items* — adequate head covering, clothing and footwear to suit local conditions; rainwear and/or an umbrella if rain is possible; a day-pack; suitable food and snack items;, sufficient drinking water, especially in hot, dry climates; sunscreen and insect repellent as necessary; basic first aid kit; mobile telephone or two-way radio for emergencies (if a local service is available).

◆ *Global positioning system (GPS)* — not an essential item but a very useful piece of equipment if the maps in use show either the universal grid co-ordinates or latitude and longitude. Some smartphones and tablets also provide this capacity.

Effective distance sampling is a complex skill that has to be learned. Observers new to the task may need to be trained to identify the target species quickly and effortlessly and learn to use rangefinders, inclinometers and magnetic compasses correctly and accurately *(see below)*. It is also helpful if they can practice the survey technique itself under supervision in a sample area before attempting survey work on their own. The importance of adequate training cannot be over-emphasised: it affects the results of a survey. Even with experienced observers a 'refresher' practice survey is worthwhile.

Using Rangefinders and Compasses

This section is intended for those new to rangefinders and/or navigating by magnetic compass.

Rangefinders

Rangefinders are commonly of two basic types: ***optical*** (which usually work either by matching two images of the target using lenses and prisms a fixed distance apart or by focussing a single image on a screen) and ***laser*** (which work by sending out a laser pulse which is reflected from part of the target back to the instrument). Because laser units have largely supplanted optical rangefinders in general use, only they will be considered further here.

The 'Bushnell Elite 1600 ARC' laser rangefinder (Figure 13) is a suitable design for wildlife work; It is manufactured in the United States and sold by sporting goods retailers who cater for hunters and archers. Other types of rangefinder may also be suitable for some tasks; it may pay to 'shop around' if you have special needs.

Figure 13. A laser rangefinder, the 'Bushnell Elite 1600', commonly sold to hunters but suitable for detection distance measurements in many types of wildlife survey.

Rangefinders measure distances within a particular range. A typical laser rangefinder operates from a minimum distance of about 5m to a maximum distance (e.g. 1000m) that is a function of its design and the reflectivity of the target. The unit illustrated is effective at measuring detection distances over a maximum range of 5-1600m from the observer. If you expect most detection distances measurements at very short distances, some retailers of surveying equipment sell relatively inexpensive short-distance rangefinders designed for special purposes, such as use by architects and the construction industry.

If you have any detections at very great distances (say, greater than 1500m), these can be approximated well enough for most purposes by measuring those distances on a detailed field map based on aerial photographs or on satellite imagery (if such a map exists of your study area). Knowing your exact position from a GPS reading can help this process. Carry such a map if possible. An alternative is to take a bearing to the detection point, move a measured distance away to the side (e.g. 25 m), take another bearing, record both bearings, then and work out the detection distance later using trigonometry.

Before using a laser rangefinder. Proceed as follows:

- *Lenses.* If necessary, clean the surfaces of the eyepieces and objective lenses using lens-cleaning tissue and preferably some lens-cleaning fluid (from camera dealers and optometrists).

- *Batteries.* Check that you have a charged battery in the instrument, and an unused spare with you in the field.

- *Operation.* Read through the instructions that came with your rangefinder. Make sure it has been set correctly for the survey conditions, and you can operate its controls.

- *Practice the task.* Go over using the rangefinder, preferably with the help of an experienced user, before going out on survey work. With a little practice most people can become very quick and accurate at measuring detection distances.

Using the instrument. The following sequence usually works well:

- *Check the rangefinder battery.* Make sure that the battery in the rangefinder is sufficiently charged for the task. (If in doubt, fit a new battery,)

- *Set the rangefinder mode.* Check that the setting of the rangefinder suits the conditions under which you are working. [You may have to refer to the instructions that came with the instrument.]

- *Choose a sighting target.* Once you disturb an animal or group of animals, they often move on. Don't sight moving animal(s) other than to notice where they go; instead, choose a suitable object to sight on *at the same distance from you* as the centre of the group where they were detected, and *at eyelevel.* Suitable objects are those likely to reflect the laser pulse back directly to the rangefinder, such as smooth white or pale-coloured vertical tree-trunks and branches, or densely-packed foliage with shiny leaf surfaces on a shrub or tree. Unsuitable targets are rough bark, the ground surface, grass and the body surfaces of many animals. Make sure you have a clear view of your target too. A single twig or leaf in the direct line-of-sight can reflect the laser pulse and give you a reading that is far too low.

- *Measure the distance.* Look through the rangefinder at the object and press the button to turn on the instrument. Line up the centre of the field of view on what you consider the most reflective part of the target. If you are having trouble holding the rangefinder steady, brace your hands holding the rangefinder against your face. Then squeeze the button to fire the laser and read the scale.

  If you don't believe the reading for any reason (*e.g.* you think an undetected small object may be in the laser's path), take a step to the side and repeat the reading. If you get a different result, repeat once more.

- *Care for the instrument.* If the rangefinder is to remain unused for some time, remove the battery to minimise corrosion or leakage problems while in storage.

Magnetic compasses

There are several different types of magnetic compass commonly used for fieldwork navigation. The best-known are perhaps the ***lensatic*** or ***prismatic compass*** (a type long-used by the military) and the ***orienteering map compass*** (e.g. the Swedish 'Silva' brand).

Examine Figure 14.

Figure 14. Three types of magnetic compass: a 'Brunton Transit' lensatic compass (left), a 'Suunto RD' compass (centre), and a 'Silva NL Explorer' orienteering compass (right). All three are suitable for line transect work, but vary in capabilities and price. The 'Silva' orienteering compass shown is cheapest, easy-to-use, fine for navigation when used correctly, and just adequate for measuring bearings to detection points if these are needed. The 'Suunto' model shown costs more, is more accurate, easier to use for taking bearings, but a little less convenient for navigation. The 'Brunton' model shown is most accurate, best for navigation and best for taking bearings, but also the most expensive. If you are on a budget and are relying on detection distances from the observer as your technique, then an orienteering compass is 'best buy'.

Avoid using any of the cheaper compasses readily available in some markets—they are often unreliable and inaccurate. They may work sufficiently well for you not to stray too far from the intended route, but will let you down if you need accurate bearing measurements to calculate perpendicular distances from the transect line. Most line transect fieldwork can be carried out with a medium-quality orienteering compass, correctly used. Whichever type of compass you have, be sure to follow its instructions carefully so can reliably measure bearings *to the nearest degree.*

Using a magnetic compass. A few aspects of compass use are important:

- ***Holding the instrument.*** When you take a compass bearing, keep it clear of steel objects that may affect the needle position when you take a reading (e.g. don't pin an orienteering compass to a clipboard with a steel clip: doing so will deflect the needle and give you a faulty bearing). Also, make sure the compass needle swings freely when you are taking readings; this usually means being careful to hold the instrument horizontally.

◆ *Following a planned transect.* If you are following a planned route based on a compass bearing, first set the compass to the intended bearing. Turn the compass to that bearing, and look along or through the compass (depending on its design) to some easily-recognisable object in the landscape along the bearing. Walk to that object, then choose another object to walk to . . . and so on until you reach the end-point. This is usually easy in open country but more difficult in forests where you may have to do this many times. If you are looking down on an orienteering compass while you do this, make sure the compass is vertically below your head and not one side (which will result in parallax error in the bearing) —see Figure 15.

Figure 15. Taking a bearing with a standard orienteering compass requires holding the instrument so it is below the mid-line of the face.

◆ *Using an older compass.* Plastic-bodied compasses are prone to deterioration over time. Get a new compass once the scale becomes hard to read or the needle doesn't seem to give the correct bearing. (Check it against another compass if you doubt the reading.) Also, avoid using any compass that contains a large air bubble.

An alternative technology. Many GPS units these days offer navigational options which you may prefer to a compass. However, remember that GPS units are battery-powered and can leave you 'high-and-dry' if the battery fails. Magnetic compasses don't have that drawback.

Also, GPS units depend on the placement of the unit is relation to the nearest navigation satellites; in many field situations, especially where there is uneven topography or dense vegetation, it is often difficult to achieve a 'fix' on a satellite; if that happens you may have to move to a hilltop or a very open site to get any reading at all.

Line Transect Sampling

3

This chapter focuses on line transect sampling procedures that can work well with many mammal and bird populations in typical 'broad-scale' land habitats — habitats in which detections are possible in any direction ahead up to the maximum recognition distance *(see 'Applicability' in Chapter 1)*. They can, with appropriate modification, also be used in special situations such as aerial surveys by helicopter. Line transects are inherently unsuitable for populations scattered about in highly fragmented habitats: such as water birds on wetlands, shore birds, and species that are either very small or react to an approaching observer before detection. Some of those situations are considered in Chapter 11.

Choosing a mode of travel. To use a line transect method effectively, the target animals should not move in response to an observer's approach before their original position is detected. Such movements include taking cover, and moving away from an observer or even towards the observer in response to their approach. Responsive movement is particularly likely if observers make themselves conspicuous in any way by sight, sound or scent. It is therefore very important for observers to travel quietly and inconspicuously on foot during a transect and, with some mammalian target species that have sensitive noses (e.g. many deer), walking a transect into the wind as well if necessary. Travel by motorised vehicles, which are characteristically noisy and produce significant ground vibration, is rarely useful unless, as with most aircraft, the vehicle moves much faster than the targeted animals.

Suitable field data sheets. A suitably-designed field data sheet, photocopied or printed out before a survey, can make a field worker's task easier. It can also help ensure that all necessary data are recorded there and then. One type of data sheet that works quite well has an initial section for general data followed by space for observational data in a rows and columns format. Figure 16 (next page) shows one type of data sheet design that has worked quite well in line transect work; it is available with the *WildlifeDensity* download.

Working as a Team

Although it is possible to carry out all tasks on your own during a line transect survey, especially if you are monitoring only one species, most people find that working as part of a team of two or three makes the task easier, more efficient, and potentially more accurate. It is also preferable from a personal safety viewpoint. If two people are available, one can act primarily as observer while the other is recorder/navigator and supplementary observer. If three people are available, the tasks of recorder and navigator can be separated, with both acting as supplementary observers. If more than three travel together

LT LINE TRANSECT ESTIMATION DATA SHEET — Transect No.: 13 p: 1

Species:	Black Wallaby	ROUTE — Starting Point:	120135
Locality:	Tooborac, Vic.	Direction (magnetic): 230°	Total Distance (m): 6450
Date:	30 Mar 2005	Finishing Point:	063105

Observer:	Amanda Brown	Weather during Transect		Temperature:	25-27°C
Recorder/Navigator:	Rachel Black	Cloud Cover:	0/8 cloud	Wind Direction:	NE
Others:		Precipitation:	none	Wind Speed:	moderate

Section Number	Starting Time	Finishing Time	Time Taken (min.)	OBSERVATIONS Distance (m)	Number	Bearing (°)	Elevation (°)	Distance (m)	Number	Bearing (°)	Elevation (°)	Distance (m)	Number	Bearing (°)	Elevation (°)	VEGETATION TYPE
1	1400	1440	30	26	1			44	1			66	2			scrub
				60	1			103	1							
2	1445	1505	20	77	1			48	1							forest
3	1505	1518	13	49	1											scrub
4	1529	1539	10													woodland
5	1539	1549	10	24	EK1											grassland
6	1549	1559	10													woodland
7	1559	1709	70	16	1			16	PY1			74	1			scrub
				28	1			148	EK3			64	1			
				73	EK1			53	1							
8	1709	1718	9													forest
9	1718	1722	4	9	1			14	1							scrub

[9 1321 1331 10 144 1 . . 52 W1 147° . 22 BT1 . 27° woodland]

Figure 16. A completed sample data sheet design for line transect surveys, filled out for a transect survey of macropods based on radial distances. General data are at the top; observations below. A footnote line shows how the designer would like data entered. Bearing data are needed only if perpendicular distances from the transect line are to be used; elevation data are needed only for surveys of arboreal species. The principal species' name has been entered under 'Species', avoiding a need to add a code for that particular species in the 'Number' column.

An uncompleted version of the sheet is available as file *LT_datasheet.pdf*.

though, it becomes hard to be inconspicuous Experience shows that most line transect surveys work best with teams of two.

Locating transects in the study area. Transect placement within a study area is an experimental design issue outside the scope of this *User's Guide*. However some placement considerations are relevant.

First, transects should be so placed that they representatively sample the entire study area, neither favouring nor under-sampling any particular part, and not favouring any part of the day. A series of well-spaced, roughly parallel, long transects spread across the entire study area is one way of achieving this. (Transects placed and orientated completely at random, although desirable on some statistical grounds, are usually unsuitable — they can either go very close to one another or cross. This doesn't work well with animals easily disturbed by observers walking through their habitat. Parallel transects walked in a random *sequence* is a usually workable compromise.)

Secondly, transects should be far enough apart to avoid animals disturbed by an observing team being driven into the vicinity of another transect. That can bias results. Observe how far the target animals move when disturbed in your study area before you decide how far apart to place transects. If you need many transects in a study area but can't afford to have them too close together, one way of achieving this is to have a first series of appropriately-spaced parallel transects in a predetermined direction, then a second series across the area at right angles to the first set. This overcomes the nearby transect disturbance problem.

Thirdly, do not without a great deal of thought site a transect so that it follows along any road, firebreak or similar open slice through the animals' habitat. For an observer looking ahead in the centre of a road, for instance, such slices usually offer an unobstructed view to the side for the first few metres, then relatively dense vegetation along the margin, then less cover through the rest of the habitat, whereas along the road ahead there is a clear, unobstructed view for a considerable distance. There is thus no consistent amount of cover between the observer and individuals in the population; that situation is treated in Chapter 11. A workable strategy is to use a local map to site straight transects across the study area independently of surface features such as roads, determine the *magnetic* compass bearing of each, then navigate by compass during the transect itself. A narrow, slightly sinuous path or trail either already cut through the area or that you cut yourself may also be suitable as a transect route provided that it samples the area representatively; this is occasionally necessary in difficult terrain but requires much more work.

Preparation for data collection. The follow steps usually precede walking a transect:

- *Finalise survey planning*. Locate your transects on a map of the study area. Adjust their positions if necessary to ensure adequate coverage. Decide which transects are to be walked each day, when, and by which teams (if more than one). Draw up a survey schedule and arrange any necessary transport. Decide whether you are to rely on radial or perpendicular distance measurements; density estimates from radial data are usually more precise but depend on careful scanning.

- *Prepare equipment.* Prepare information for each survey team, to include: a map of the area with the transect locations marked, how to recognise starting and finishing points, what bearings to follow en route, any other transect information, how to recognise the targeted species, how to classify habitats, and any other pertinent information. Prepare sufficient data sheets for the task.

Collect together the relevant number of rangefinders, compasses and all other equipment and ensure all are in working order. (Having a spare or two is often a wise move.)

◆ *Decide team roles*. If appropriate, divide personnel into teams and arrange individual roles within teams. Observers need to have excellent vision, have the skills to use a rangefinder and be thoroughly familiar with the species. Recorder/navigators should be people able to classify vegetation structure correctly and quickly, use a magnetic compass, monitor progress and develop an excellent set of field records. Allocate people to teams and transects.

◆ *Issue equipment.* Hand out all the equipment for which you are responsible, and check that each team has all that is needed.

◆ *Practice using equipment and following set procedures*. Make sure all observers gain practice in measuring with a rangefinder, know the diagnostic features of the targeted species and what data are needed. Make sure all recorder/navigators can use the compass to correctly follow a planned route, know how to recognise habitat types, and know how to enter field observations in all parts of the data sheets. It helps if all team members can identify the targeted species in the field.

◆ *A practice session.* If you have inexperienced people on teams, running a short practice transect and supervising it carefully is well worth the time. This is worth doing as a reminder even for 'old hands'.

The remaining procedural points in this section are particularly important, They need to be observed if subsequent analysis using the *WildlifeDensity* model is to be valid.

At the start of a transect. Observer tasks below have been marked 'O', recorder tasks 'R' and navigator tasks 'N '. If you are on your own, all tasks are relevant; for a team of two, the recorder/navigator needs to carry out all the 'R' and 'N' tasks.

◆ *(O)* You are to include in your survey only those animals you see in front of you as you head along your transect: i.e. from 90° to the left of your transect line around an 180° arc in front of you to 90° to your right. If any target animals are visible in front of you at the start, do not include them in your data because they would have been visible from a point behind you. (Any that you see ahead of you at the end of the transect take their place.) However, keep track of where they move once disturbed so you don't count them as a 'new' record later.

◆ *(R)* Fill out on your data record the transect identification, date, principal target species, first and last names of team members, and weather conditions at the start (precipitation, cloud cover, wind conditions, temperature). Double-check what to enter as you go. Decide how you are to classify the vegetation cover you see ahead of you along the transect.

Number the first transect section '1', record the starting time (24h format: e.g. '1412') and the vegetation type of the first section ('forest', 'grassland', etc.). You are to end that section once the vegetation changes to another type, then start Section 2; and so on.

◆ *(N)* Set the compass to the appropriate magnetic bearing and look for a distinctive object (e.g. tree, rock) to walk to. (You will do this again once you reach that object . . . and so on.)

During the transect. The next few points apply throughout the transect.

◆ *(O): Travelling forward.* Move forward inconspicuously and quietly. Pause when animals flush or are otherwise disturbed. Try to keep the overall pace even; walk a little faster for a time if you have been standing for a while taking measurements.

Scanning ahead. Scan the full 180° arc ahead of you as evenly as you can, scanning from left to right and back again, trying to give all directions equal attention. Try to do this continuously, not in a staccato fashion (e.g. not stopping to scan, then walking 10 or 20 paces and stopping again). Make sure someone else is watching for animals when you are counting or measuring distances. In heavy cover, if you flush an animal you can identify by sound, count that as an observation too (but not if it simply calls without flushing).

Do not count any animal calls you hear without actually seeing the animal. This technique doesn't work with sounds because modelling their detectability is too complex. Use sounds only to help species identification.

Counting animals. Once you see a target animal, or a group of them (i.e. a few close together), first make sure you have identified it correctly, and it is ahead of your position. Then count the number you can see only with the unaided eye. (Do not use binoculars to count a group, because doing so alters the probability of detection.) Notice also where an individual or group goes once disturbed, so you know not to count it as a new observation if you see it again. Include in a group all animals relatively close to the selected central point; better precision is achieved in survey results if your data are made up of many individual observations or small groups (at different distances) rather than just a few large groups.

Overlooked individuals. Animals that you overlooked and are now behind you should not be counted unless they subsequently move forward and pass your position. If you are progressing slowly this can happen surprisingly often in open country with population members that are well away to the side. If they overtake, count the number in the group but do not measure the detection distance. (The recorder will note them differently in the field data record.)

Distance measurement. Measure the horizontal distance to the point where the individual animal or the approximate group centre was at the moment of detection, choose some fixed object at the same distance to sight on, and use a rangefinder to measure the detection distance as accurately as you can. For individuals that flushed, were heard but remained unseen, try to work out the approximate flushing point and measure the distance to that. Measure all distances if at all possible.

Measuring angles. If density estimates are being based on perpendicular distances, also measure the compass bearing to the detection point. For populations above eye-level (e.g. arboreal species), use an ***inclinometer*** to measure the angle of elevation to the detection point.

Reporting data. Report all data to the recorder. If, after moving on, you see additional individuals in a group you have already counted, count the additional ones and take a new set of measurements. For the purposes of the survey, treat them as a new group at a new distance.

◆ *(N): Using the compass.* Try to stay as close to the correct transect line as you can. You should not have to talk to others about the walking direction unless something is clearly wrong; others can be asked to trust your navigation and stay in your vicinity throughout the transect. Use the compass continually, and try to keep track of where you are on a map. Make sure too you don't walk ahead of your observer.

Other tasks. As you go, you are also to look out for the target species and draw the observer's attention to any sightings you make. Especially, watch out for animals you see ahead whenever the observer is preoccupied (say, with measurements).

◆ *(R): Beginning and ending transect sections.* As the transect proceeds, watch your surroundings continually. Be prepared to end a transect section and begin a new one at an appropriate moment once the visibility ahead begins to alter appreciably as you enter a different habitat. Record each observation *as in the section where you are standin*g, not in another vegetation type if that is where an animal happened to be standing. (For the density estimation task, cover affects detectability by modifying visibility through it; so it is important to allocate a detection to the vegetation type *you are looking through*.) End the section by writing in the finishing time and the starting time of the next section; then enter the number, starting time and habitat type of the new section. And so on. (You may also, if you wish, end sections every 10 minutes or so in long stretches of fairly unchanged habitat, in which case a new section will of course have the same habitat type as the previous one.)

Monitoring progress. If you notice that the team is tiring, or requires a break for other reasons (food, drink, etc.), end the section at an appropriate moment. Don't begin a new section until the team is ready. An occasional 'break' can improve team members' concentration.

Recording observations. Record all individual or group data that the observer collects, in the appropriate standard format (see sample data sheet). When you record overtakes, write down the number counted and either enclose the number in parentheses, e.g. (3), or use a zero for the detection distance; the *WildlifeDensity* program will interpret and observation at zero distance as an overtake.

Long-distance observations. In the case of sightings at very long distances in open country, you may be able to help measure the detection distance from the map if you know precisely where you are. Using a GPS unit can help with this. (Keeping track of times when you cross map features such as roads or watercourses may also help you know precisely where you are.)

Weather data. Record weather data at intervals through the transect (e.g. each time you move to a new data page), so that an overall account becomes possible from the records once the transect has finished.

Walking pace. Try to keep the overall walking pace fairly even throughout the transect. A strolling pace is usually best.

Ending a transect. Finally, watch for the planned end point.

◆ *(O): Animals ahead at the end point.* Include in the transect any animals visible ahead of you at the end-point.

◆ *(R): Finishing the task.* Complete any unfilled general data on your data sheets,. Look for and correct any other gaps in your data record. Number all data sheets in the correct sequence.

Procedures for field staff are summarised in the handouts *LT Field Observer Procedure.pdf* and *LT Recorder-navigator Procedure.pdf* in the *WildlifeDensity* data sheet templates.

Fixed Point Sampling

4

Chapter 4 deals specifically with fixed point counts. If you are using a line transect technique, and your species of interest is highly mobile (e.g. many bird species), you may need data on its movement rate. If that is so, but you are not using fixed point counts, bypass this chapter and go directly to Chapter 5.

This chapter sets out fixed sampling procedures suitable for highly mobile mammal and bird populations that live where you can locate a sampling point within its habitat and detections are possible in any direction up to the maximum recognition distance (see 'Applicability' in Chapter 1). The technique is unsuitable for species that move about relatively little, or are too small to be seen easily. It is not recommended either for populations in habitat patches that are very small or have awkward shapes, such as narrow strips of roadside vegetation through open countryside.

Suitable field data sheets. A suitably-designed field data sheet, photocopied or printed before the survey, can make a field worker's task easier and help ensure that all critical data are recorded there and then. One type of data sheet that works quite well has an initial section for general data followed by space for observational data in a rows and columns format. Figure 17 (next page) shows a data sheet design suitable for fixed point sampling. It is downloaded with *WildlifeDensity*.

One species, or many? In line transect work, it is usual for only one or a small number of species to be the targets of interest because the technique itself consumes a significant part of the observer's concentration time. Standing or sitting at a fixed point is a different matter: there is often enough time to observe many species, e.g. all bird species at the site.

A team, or working alone? Unlike line transect surveys, when it can help to have a team of two or three together, the point count often works best when you are on your own. You have to be inconspicuous enough for target animals to approach your observation point without responding to your presence before you see them. Having two or three people together makes this more difficult. If you work as a team of two, one way of overcoming this problem is to have just an observer and a recorder, with the recorder sitting still and silently near the observer's feet.

Locating sampling points in the study area. Sampling point placement within any study area is an experimental design issue outside the scope of this *User's Guide*. However two principles are relevant. First, observing points should be so placed that they representatively sample the entire study area, neither favouring nor under-sampling any particular part. Secondly, each point needs to be well within a recognised habitat type.

Decide your sampling strategy. If the strategy you choose puts any sample point on a margin between one habitat and another, move it just far enough to lie within the nearest clearly-recognisable habitat type in the vicinity.

FIP FIXED POINT ESTIMATION DATA SHEET

Census Code: p:

Locality:

Date:

Weather during Sampling

Cloud Cover:

Precipitation:

Temperature:

Wind Direction:

Wind Speed:

Observer: Recorder:

Sampling Point No.	Starting Time	Finishing Time	Time Taken (min.)	OBSERVATIONS												VEGETATION TYPE
				Species Code	Distance (m)	Number	Elevation (°)	Species Code	Distance (m)	Number	Elevation (°)	Species Code	Distance (m)	Number	Elevation (°)	
9	1321	1351	30	SWP	45	2	24°	GCW	84	3	12°	SWP	31	1	34°	forest

Figure 17. A sample data sheet design for fixed point surveys. General survey data are at the top, spaces for observations below. A footnote line shows how the sheet's designer would like data entered. Elevation data are needed only for surveys of arboreal species. The sheet is designed to accept multiple species records.

The sheet is available in the *WildlifeDensity* download as file *FP_datasheet.pdf.*

Preparation for data collection. The follow steps usually precede fixed point sampling:

◆ ***Finalise survey planning.*** Locate your sampling points on a map of the study area; adjust their positions if necessary. For each day of your survey, decide which points are to be sampled, at what time, and by whom (if more than one observer). Draw up a sampling schedule. In planning a sequence of samples for a day, try not to match any existing movement pattern of the animals (such as moving to and from a water point). A more-or-less random sequence can help achieve this (even though it might be less convenient). Arrange any necessary transport.

◆ ***Prepare equipment.*** Prepare preliminary information for each observer. Include a map of the area with the sample locations marked and information on how to recognise their precise locations, how to recognise the targeted species, how to classify habitats, and any other pertinent information. Precise sampling locations can be given a UMG grid reference (or the relevant latitude and longitude). Field workers can be supplied with a GPS to help locate sampling points, or the sites can be suitably marked (e.g. with coloured flagging tape) beforehand. Prepare enough data sheets, and collect together the required number of rangefinders, inclinometers, binoculars and any other equipment you are using, and ensure all are in working order. (Having a spare or two is often a wise move.) Check that everyone has some way of knowing the time.

Another piece of equipment that some observers like to use is an old office stool with a seat that rotates. This can serve as a seat at the sampling point which makes long periods of observation less tiring. The stool needs to be readily portable and able to survive inclement weather.

◆ ***Decide team roles.*** If you are working in pairs, divide personnel into teams and arrange individual roles within teams. Observers need to have excellent vision, the skills to use a rangefinder and an easy familiarity with the species. Recorders should be able to classify vegetation structure correctly and develop an excellent set of field records. A single observer needs both sets of skills. Allocate observers to sampling points.

◆ ***Issue equipment.*** Issue all the equipment for which you are responsible. Check that each person has all the items they need.

◆ ***Practice using equipment and following set procedures.*** Make sure all observers gain practice in measuring with a rangefinder, can use an inclinometer to get an angle of elevation in degrees, know the diagnostic features of the targeted species and what data should be recorded. (Bearings to a detection point are not needed with fixed point data, but elevation angles often are.) Make sure too that observers can identify the key targeted species in the field. Ensure all participants can locate the sampling points, know how to recognise the habitat types, and how to enter field observations on the data sheets.

If you have inexperienced people on teams, running a short practice beforehand and supervising it carefully is well worth the time. This is worth doing even for ‘old hands’.

Finally, it makes life much easier if observations at each sample point begin some time after arrival (say, 10-15 minutes), then last for a uniform period of time. Experience suggests that, for many bird species, a fixed period of observation from 30 minutes to 1 hour long works well. If you have more than one observer, make sure that all observers wait for the appropriate period of time before beginning, and that all sample durations are identical.

The remaining procedural points in this section on fixed point sampling are particularly important, and need to be observed if subsequent analysis using the *WildlifeDensity* model is to be valid.

Before beginning. Observer tasks below have been marked 'O' and recorder tasks 'R'. If you are on your own, all tasks are relevant.

- *(R):* You are to locate the sampling point and move to it, taking all necessary equipment with you, and find an appropriate place to sit near your observer. If the point is on a margin of more than one habitat type, move your point 30m or so into one of the habitat types (toss a coin to decide which one).

  Fill out on your data sheet the survey code (if you have one), adequate locality information, the date, the first and last names of team members, and weather conditions (cloud cover, precipitation, temperature, wind conditions). Be sure you know how to classify the vegetation cover around you. Double-check each entry.

  Number the first sampling point on the data sheet, and time the period up to the start. Give the 'OK' to your observer, record the starting time (24h format: e.g. '1412') and the vegetation type ('forest', 'grassland', etc.). Keep track of the time; you are to end sampling the instant the agreed period ends.

- *(O):* Your task is, first, to move quietly to the sampling point, prepare all equipment, then wait for the agreed period of time for normal animal activities to resume around your sampling point.

  Once the period begins, you are to rotate very slowly the full 360° if possible (or a lesser, agreed number of degrees if necessary). Watch out for any individuals that come into view around, above and below you. *Do not count any animal calls you hear without actually seeing the animal;* this technique doesn't work well with sounds. Use the sounds only to help identification.

  You are then to determine the species, measure the horizontal distance to the detection point, count the number of individuals at the detection point and measure its angle of elevation (if it is an arboreal species).

During the sampling period. The next few points apply to the data collection task itself.

- *(O):* Begin to rotate very slowly and steadily. Scan the full 360° arc around you as evenly as you can, scanning up and down too, and trying to give all directions equal attention. Once you see a target animal, or a group of them (i.e. a few close together), first make sure you have identified it correctly. Then count the number you can see with the unaided eye. Do not use binoculars to count a group, because doing so alters the probability of detection; use binoculars for identification only or — better — identify the species by its calls.

  Watch where the individual or group goes when it is in your vicinity; once it moves far enough away not to be observable any longer, treat the observation as complete. If the individual or group moves back later, treat the second detection as a new observation. (If you do this correctly, then if you were to spend twice as long at a sampling point you would — on average — make about twice as many observations.)

  Make sure you measure the *horizontal* distance to the point where the animal or approximate group centre was at the moment of detection, using some fixed object to sight on, and measuring as accurately as you can. Do not measure the direct-line distance to the animal itself unless you are

prepared to do some trigonometry later to work out the horizontal distance. For species that tend to move about either well above or below observer eye-level, use an inclinometer to measure the angle of elevation from your eyes to the detection point.

If, after a group moves on, you see additional individuals in a group you have already counted, count the additional ones and take a new set of measurements. For the purposes of the survey, treat them as a new group at a new distance.

◆ *(R):* Record all individual or group data that the observer collects in an appropriate standard format (see sample data sheet). In the case of sightings at very long distances in open country, you may be able to measure the approximate detection distance from the map.

Keep watch on the time and end the sampling period immediately the pre-determined time ends. (Some form of low volume alarm clock may help.) Do not include any observations made outside the scheduled time period, no matter how interesting they may be.

[The first part of Chapter 5, *Animal Mobility and Topography*, is also relevant if you are collecting fixed point data.]

Animal Mobility and Topography

5

The first part of Chapter 5 deals with animal mobility — why it is important, when you need data on it, and how to collect movement data you can use to help estimate population densities. How to measure topography — when necessary — is treated later in the chapter. If you are using a line transect technique and your species moves more slowly than your survey teams travel, then only the topography section is relevant.

Measuring Animal Movement Rates

When — and why — are movement data needed? Movement by birds and mammals can have profound effects on the numbers you see. If you stay for a long period in one place, animals will come into your vicinity from time to time while foraging or moving about for other reasons. The fixed point sampling procedure used by *WildlifeDensity* and other distance methods in fact depends on that happening. But if you walk a transect when your target species is highly mobile, and you collect enough data, you may notice that the number of detections you make is related to your own rate of travel: the slower you travel, the more detections you make. Conversely, the faster you go the fewer detections you make. Look at Figure 18 on the next page.

The relationship between observer travelling speed and the number of contacts during a line transect can be modelled if you know the average movement rate of animals in the population. The model can then be used to remove the effect of movement on your data. *WildlifeDensity* can do this for you provided that you supply it with data on your species' average movement rate. Similarly, with fixed point data, *WildlifeDensity* can estimate a population density from detection data provided that the program is given the species' average movement rate. This means you may need to collect appropriate data on movement rate.

Animal movement rates differ greatly from species to species. They depend very much on the animal's body structure and on its foraging and other movement behaviour,. Swifts and swallows, for example, forage on the wing, spend much of the day in flight, and consequently have very high overall movement rates. One effect of this is to make them appear more abundant than they really are — the same individuals may cross and recross an observer's path many times over a brief period. Others, like some of the large grazing herbivores, are relatively sedentary and move about comparatively little.

The next few pages deal with ways of collecting animal mobility data in the field, then using it to calculate an overall population movement speed for a species.

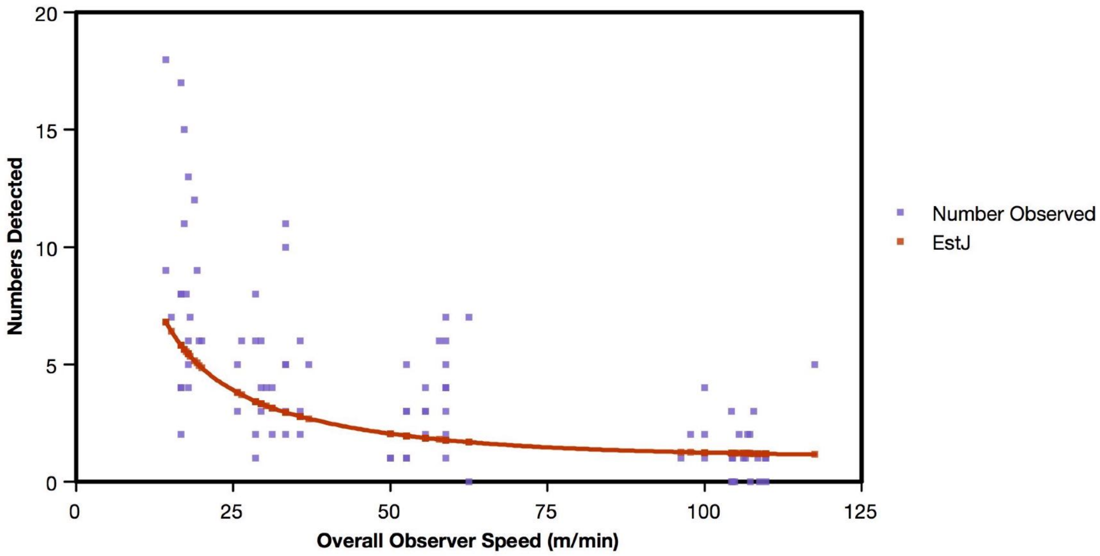


Figure 18. The relationship between the overall rate of travel of an observer on a line transect and the number of detections made *(blue dots)*. The population is of an active songbird, the insectivorous grey fantail *(Rhipidura albiscapa).* The observer walked or cycled a transect 91 times, at a variety of speeds. At slower observer travelling speeds the number of contacts increased, and *vice versa.*

The relationship can be predicted approximately *(coloured line)* when the average movement rate of individuals in the population is known (averaging about 117 m/min in this case). This makes it possible to correct for the effect of observer speed on the numbers detected. If the numbers detected are divided by the relevant value of a predictive model (EstJ), the resulting numbers no longer alter with travel rate. *(Data: R.Plant)*

What you ultimately need to know is the average rate of *translational movement* in a horizontal plane, i.e. the rate at which the whole animal moves from point to point in the landscape. Translational movement is different from the movements of, say, jaw muscles, which do not affect its position in two-dimensional, horizontal space.

To calculate an overall movement speed, you need to know how many types of translational movement your species shows, what proportion of the animal's time each type occupies, and how fast each s.

Types of movement data. With most birds and mammals, an individual's movement rate is uneven. Part of its time is spent stationary, part in what is usually relatively slow movement as it feeds and interacts with others. Part is occupied in travelling from one part of the landscape to another (*e.g.* moving from shelter to a food source and back again, or from one feeding site to another). Comparatively rarely, a very small part of its time is spent in very rapid movement to escape danger (*e.g.* from a predator) or in rapid pursuit of its prey (*e.g.* a falcon stooping).

The proportions of an animal's time spent on the different movement types vary greatly from one species to another, and sometimes with time of day and season of the year. So may the speeds at which they move. With many species, though, it is only the travelling between one feeding site and another, or between feeding sites and shelter, that has much impact on their overall rates of movement.

That travelling speed is usually relatively rapid (even though it may only happen in perhaps 3-5% of the day or even less).

Exceptions are species that depend on their mobility to capture food, as shown by the insectivorous grey fantail (Fig.18), other birds and bats that also capture insects in flight, and many birds of prey. Some observation of your target species will show which type of movement accounts for the bulk of its translational movement across the landscape. Usually it is the travelling movements from one feeding or shelter point to another (*e.g.* from tree to tree) though, with a few species, most of their movements may be in foraging.

You usually need two types of data to compute an overall movement rate:

- its *movement proportions,* the average proportions of the animal's day that population members spend in significant translocational movement; and
- its *movement speeds,* the average speeds at which they move during those translocational movements.

Most species' translocational movements can be classified into one of four basic types:

◆ *'Stationary' (S):* The animal does not change its position in relation to objects around it (though it may be feeding, grooming, vocalising or carrying out some other form of behaviour — e.g. sleeping — while it remains stationary). This is usually the commonest type of 'movement'. It may occupy much of its time. Most animals do n't move about when they don't need to.

◆ *'Walking' (W):* Local movements using either a walking gait (many herbivorous mammals), or hopping (especially small birds), or pentapedal movement (e.g. the 'four-legs-and-a-tail' movements of macropods). Such movements usually take place during localised foraging for food items. Walking movements may occur often, but are usually comparatively slow.

◆ *'Travelling Movement' (T):* Movements carried out by an animal during normal relocation from one place to another, as when moving from one feeding site to another, or travelling between a feeding area and shelter, or migrating. The animal moves steadily (and usually quite efficiently) without being under stress. Running, hopping or flying are the means used. The average speed of this type of movement can be relatively high, and it usually brings about most significant changes of location during a typical day.

◆ *'Flight Movement' (F):* Movements carried out by an animal when under stress — as in flight from a potential predator or interaction with a territorial challenger — and movement by a predator pursuing prey. Flight movements are commonly very rapid but brief, and — with many species — are also uncommon. With some species they may not occur at all on a typical day.

[Additional categories may be necessary for a few species. However experience suggests that these four types are usually enough for work on movement patterns.

If only an approximate idea of the amount of movement is needed — and that is often the case — the 'walking' category can be included with the 'stationary' data, and the 'rapid flight' category with the 'travelling' data, This produces a simplified but usually adequate data set.]

Collecting movement proportions data. To calculate the overall movement rate, you need enough data to reliably estimate the proportion of the day over which each movement type occurs. Typical proportions are shown in Table 1 below, followed by a few suggestions on how to collect such data.

Table 1. Typical movement proportions data for a species population. 'Walking' covers the range of relatively slow movement types used by individual birds and mammals while foraging on the ground or amongst foliage; 'travelling' refers to the types of more rapid movement used to move the individual from one place to another; 'flight' refers to the fastest movements, used rarely, and in situations such as prey fleeing from a predator, or a predator pursuing prey.

Type of Movement	Proportion	Percentage
'stationary' (S)	0.745	74.5
'walking' (W)	0.224	22.4
S + W	0.969	96.9
'travelling' (T)	0.031	3.1
'flight' (F)	0	0
T + F	0.031	3.1
total	*1*	*100*

- *Personnel.* To collect data on the proportions of time members of an animal species spend on their various types of movement, a team of two people is best — an observer (O) and a recorder/timer (R). The observer keeps the animal(s) under observation and classifies and reports its movement types, while the recorder keeps time and records the data. It is possible though more difficult for one observer to perform both roles.

- *Equipment required. (R):* clipboard and plastic cover, writing implement, blank movement proportion data sheets, analogue wristwatch with sweep second hand or a digital timer that shows seconds.

(O): binoculars only.

(R+O):: food, drinking water, suitable clothing, rainwear, headgear and footwear, sunscreen. Suitable data sheets (Figure 19) come with the *WildlifeDensity* program.

- *When to collect data.* Decide the time of year and time of day over which observations are to be made. If maximum precision is needed, be prepared to confine observations to a predetermined period of time and set of observing conditions. For example, sample the movement proportions over the same season and time of day as the survey observations, and in the same or similar habitat types. However experience suggests that going to that amount of trouble can be 'overkill' — one single, relatively extensive set of data is usually sufficient for virtually all surveys of that species thereafter.

Be sure that, when collecting the data, you avoid times of consistent unusual movement (e.g. a time of migration) and weather conditions that are very different from those during your surveys.

MOVEMENT PROPORTIONS DATA SHEET

Species:	Weather during Sampling:	Temperature:	
Locality:	Cloud Cover:	Wind Direction:	
Date:	Precipitation:	Wind Speed:	
Observer: Recorder/Timer:	Movement Types:	S — stationary; W — walking, hopping (birds), grazing; T — travelling (relocation); F — flight (escape, pursuit)	

TIME	OBSERVATIONS				TOTALS				
(24h)	1st 3	2nd 3	3rd 3	4th 3	S	W	T	F	Total
[1322	S S W	S S T	T T S	S S W	7	2	3	-	12]

Figure 19. A data sheet suitable for movement proportions data collection. The sample data in the first line was collected at twelve 5-second intervals over one minute. If observations are made at 10-second intervals, each data line covers two minutes' observations.

This data sheet is available with the *WildlifeDensity* software as file *MP_datasheet.pdf.*

◆ *Spacing between observations.* Decide the time interval to be used for movement observations. Every 5 seconds is usually a convenient interval, but every 10s may be preferable if a very long time period is involved. The recorder/timer is to say 'Now!' or use an instrument to produce a sound at those intervals during observations, and the observer is to classify and report the type of movement observed at that instant. When only one person is observing, the longer time interval may be needed to allow time for recording between observations.

Decide also the maximum period for which each *individual* is to be watched. (This will be influenced by the species' abundance in the study area; if there are many individuals about, 15-20 minutes of observations on one individual may be sufficient, followed by the immediate semi-random choice of another. If there are few individuals about, you may have to use much longer periods of observation.)

◆ *Suitable field data sheets.* Photocopy some suitably-prepared data sheets beforehand (see Figure 19). Once in the field, complete the details at the head of the first data sheet. Four columns have been allowed on this data sheet for each minute of 5-second observations, i.e. 12 observations in all. A sample set of data has been included in the first row of the prepared data sheet as an example.

◆ *Making observations.* When you are ready to collect movement data, select a typical member of the species to begin with: for example, the third one you see. Look at it and satisfy yourself that its behaviour will be representative of the population; if not, choose the next you see. Place yourselves (observer and recorder) far enough away from the animal not to affect its movements but where you can see it clearly with binoculars. If the animal seems affected by your presence, stay there quietly for some time and wait for it to resume normal behaviour before you begin.

> *O:* Stand or sit comfortably, and start watching the animal, using binoculars as necessary. Prepare to classify the type of movement you see at the *precise instant* of observation (*e.g.* the moment your recorder says "Now!"). Then say: "stationary", "walking", "travelling", or "flight" [or just "stationary" or "travelling" if the simpler approach is taken], or even just "S", "T", etc.
>
> *R:* Write down the time in the first column of the prepared data sheet, using 24h clock notation, and start watching your timepiece. Say "Now!" aloud at each predetermined interval, then record an 'S', 'W', 'T' or 'F' in the appropriate place when the observer announces the behaviour observed.

If you are using the Figure 19 table and a 5-second interval, put the first three observations in Column 2, the next three in Column 3, the next in Column 4 and the final three in Column 5. (Total them later.) Then move immediately to the next minute's observations, recording them in the next row of the data sheet. Put a dash if you miss an observation.

◆ *Keeping up with your animal.* Try hard not to miss any observations. If the animal moves out of sight (and it will), move yourself as rapidly as possible to where you can keep it in view — even if that means sprinting or cycling across the landscape! Try hard to avoid missing any travelling movements. If you are unsighted for a movement, fill in the blank with a 'best guess' if possible to avoid distorting your results.

◆ *At the end of the day.* Count the numbers of observations in each category, calculate a grand total, then express each movement type total as a proportion of the grand total. In the simplest case — where only 'stationary' and 'travelling' observations are considered — this result can represent the proportion of the survey time when individuals are moving about. For most birds and mammals, it is

typically less than 5% (.050) of the day though, especially for bird species that feed on the wing (such as fantails, swallows and swifts), the proportion of time on the wing may be much higher.

Collecting data on movement speeds. For this, you need to know how the average distance each movement type moves (displaces) the animal in one minute. As described above, a typical individual in a population will show most types of movement pattern during a day. The 'average day' will involve long periods of relative inactivity punctuated by occasional bursts of translocation activity whenever it moves from one place to another.

A typical daily route, too, is often a meandering path across its home range. This means that conventional radio-location data made on individual radio-tagged animals at long time intervals are not usually of much use as a basis for measuring total distances travelled. They don't show the meanders between successive radio 'fixes'. For example, the 'travelling' (flying) movements of most birds are rarely direct, often involving twists and turns (or even circles). Flights are also of greatly varying lengths.

The overall movement speed (total distance moved/total time taken) is highly variable too. Flying speeds characteristically increase with distance flown because birds must initially accelerate from zero speed, then decelerate to stationary at the end. As a result, the shorter the flight, the greater the proportions of time spent accelerating and decelerating. Air currents also affect flying speeds: ground speed is generally faster for downwind flights and slower (or even negative!) for upwind flights, while cross-winds sometimes produce a curved path of continually varying speed. (The same holds true for non-flying mammals and flightless birds, but to a much lesser extent.) The data collection methods used must take account of these things *e.g.* choose windless days to collect the data.

For travelling movements at least, one needs a set of measurements of such 'journeys', recording the over-ground distance travelled and the time taken on each occasion. (Ignore movement in a vertical plane: i.e. up or down—map distances in the horizontal plane are the goal.)

Measurements are needed too for *a variety of individuals* of the species of interest, at the sorts of places and times used for survey work. Make sure you take enough measurements to be satisfied with the average speed calculated. If you can't sample many movements for some reason, then truncate the data by omitting both very long and very short flights from the calculations used to get your 'best estimate'.

- ***Calculating a movement speed.*** Overall travelling speed is estimated by adding together all the various over-ground distances travelled, totalling all the times measured, then calculating:

  Overall travelling speed = total distance travelled (in m.)/total time taken (in min.)

  If you wish to calculate standard errors, work out the overall speed of *each* translocation, then use the resulting set of speeds as the data from which to calculate the measure of spread.

- ***Measurement methods.*** There are various ways of measuring how fast an animal moves each journey. One method that works well after some practice is for observers to equip themselves with a good quality magnetic compass, a laser rangefinder and a stopwatch. Time a movement, not necessarily from beginning to end, but part of it: from a recognisable 'start' point to a recognisable 'end' point. Measure the bearing to the start point and its distance. Then do the same for the end point. Record all data. The straight-line distance between the two points can then be calculated by

MS MOVEMENT SPEEDS DATA SHEET

Locality:	Weather during Sampling: Temperature:
	Cloud Cover: Wind Direction:
Date:	Precipitation: Wind Speed:
Observer:	Movement Types: S — stationary; W — walking, hopping (birds), grazing;
Recorder/Timer:	T — travelling (relocation); F — flight (escape, pursuit)

Species	Movement Type	Starting Position		Stopping Position		Comment	Time Taken	Distance (m)	Speed (m/min)
		Bearing (°)	Distance (m)	Bearing (°)	Distance (m)				
[emu	T	48°	702	30°	551		20 min	244.9	122]

Figure 20. A data sheet designed for movement speed data, with a sample set of data in the first line. Most column data can be completed in the field; however the last two columns ('Distance' and 'Speed') can be filled out only after computations using the Cosine Rule *(see text)*.

This sheet is available in the *WildlifeDensity* software as file *MS_datasheet.pdf.*

trigonometry, using the Cosine Rule of mathematics. This works well provided that the movement was fairly direct or was a relatively straight portion of a longer, more circuitous path.

Remember that, to measure the total distance travelled, you need the total over-ground distance between the animal's starting point and finishing point for each translocation movement. If the route had turns in it, this means watching the route taken, then using the rangefinder to measure one or more point-to-point distances and adding these together.

◆ *Personnel.* Again, collecting data on animal movement speeds is better done with two people: an observer *(O)* and a recorder/timer *(R)*. Both need to be prepared to sprint (or climb on a mountain bike) if and when the need arises. The tough decision as to the total distance travelled is often helped by some discussion between team members.

◆ *Equipment required. R:* clipboard and plastic cover, writing implement, and suitably-designed data sheets with room for locality and time data at the top, then columns for time taken, initial bearing and distance, final bearing and distance, and comments. *O:* stopwatch, laser or optical rangefinder, magnetic compass and binoculars. *O+R:* food, drinking water, suitable clothing, rainwear, headgear and footwear, sunscreen.

◆ *When to collect data.* Decide the time of year and time of day over which observations are to be made. Avoid windy weather, sampling times near dawn or dusk, and times of year when individuals are migrating (unless of course you are also collecting transect data at such times).

◆ *Suitable field data sheets.* Prepare some suitable data sheets beforehand: a sample data sheet suitable for movement speed observations is shown in Figure 20 (previous page). Once in the field, complete the details at the top of the first data sheet.

◆ *Number of samples.* Decide also how many different individuals you intend to use for measurements. (This will, again, be influenced by the species' abundance in the study area; if the population is abundant, aim for data from at least 5 different individuals.

◆ *Making observations.* When you are ready to collect movement data, begin by selecting a, typical individual member of the species. Reduce possible bias by selecting, say, the third one you see. Satisfy yourself that its behaviour is representative of the population you are interested in. Place yourselves far enough from the animal not to affect its movements, but where you can see it. If the animal seems affected by your presence, wait for it to resume normal behaviour.

Begin watching the animal, with the stopwatch ready. Wait patiently for it to begin movement, then time the movement from a start point to an end point, moving yourself if necessary to keep it in view. Then measure the total over-ground distance travelled. Record all data, with times in minutes and decimals of a minute (or in seconds, converting them later), with bearings in degrees and distances in metres.

It is OK to *carefully* encourage movement if you find yourself watching a stationary animal for what seems an unduly long time. However, if you do this, make sure you don't *startle* the animal or its movement speed will be atypically high. *Persuade* your animal to move a little 'grudgingly', if you can, by approaching very cautiously.

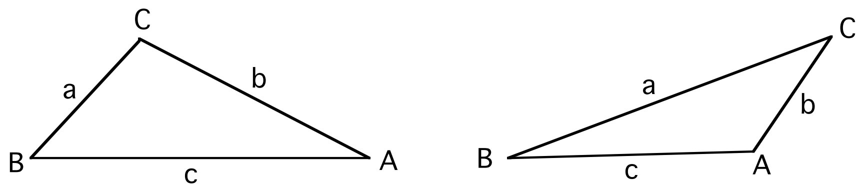
◆ Keeping up with your animal. Also, try hard not to lose the animal once it begins to travel. If this does happen despite your best efforts, try measuring both distance and time right up to the moment when it disappeared from view.

Working out movement rates. Count up the number of measurements made. Then, for each measured movement, work out the distance travelled. This involves first calculating the angle between each pair of bearings, then using the Cosine Rule of trigonometry.

◆ ***Angles between bearings.*** Enter all your data on a spreadsheet (e.g. Excel or Numbers). Calculating the angle between the two bearings in each pair is simply a matter of subtracting one bearing from the other. This needs care: if one bearing is just west of north (say, 351°) while the other is east of north (say, 23°), the difference between them is not 351 - 23 = 338° but 32°. So; if two bearings are either side of north, first add 360° to the more easterly bearing. The calculation is then:

Corrected easterly bearing = 360 + 23 = 383°
Angle between bearings = 383 - 351 = 32°

◆ ***Distances travelled.*** To work out the distances travelled in each case, first look at the diagrams below. In each triangle, the observer is represented as at Point A, the measurement begins when the animal is at Point B and ends when it reaches Point C, after moving an unknown distance a. B is c units from A, and C is b units from A; and both distances are measured. The observer has also measured the compass bearings to B and C; subtracting one from the other has given the angle between them (angle A).



For any triangle, the Cosine Rule is:

$$a^2 = b^2 + c^2 - 2bc\cos A$$

To determine *a*, the distance travelled, calculate:

$$a = \sqrt{(b^2 + c^2 - 2bc\cos A)}$$

Computing the cosine of angle A (cosA) may cause a problem if the angle has been measured in degrees and the cosine table used to read cosA is based on radians. If that is so — as it is in programs such as Excel — first convert the angle to radians by calculating:

$$angle\ A\,(in\ radians) = \frac{\pi\ .angle\ A\,(in\ degrees)}{180}$$

For each species and movement type you measured, calculate a best estimate of speed by totalling distances and times, then dividing as described above. Other statistics are then calculated from these.

Calculating a species' overall rate of movement. You can now calculate your estimate of the overall movement rate *(u)* of each species of interest as follows.

- ***Simpler case — only travelling speed measured.*** If you are only interested in an approximate measure of speed (and have chosen to disregard 'walking' and 'flight' movements as separate categories) then:

  overall movement rate (u) = overall travelling speed x proportion of time travelling

  If speed has been measured in m/min, then this is appropriate for the overall movement rate as well.

- ***All movement types measured.*** If you have included all movement types in your data, then:

  overall movement rate = ∑(type speed x type proportion)

  where ∑ indicates the sum of each of several bracketed calculations (one for walking movements, one for travelling movements, one for flight movements).

Record all results. The overall movement rate calculated for each species can be then entered into *WildlifeDensity* whenever it is needed.

Using Topographical Information

Figure 8b (p.19) showed that, as detection distances increase, topography has a similar effect on detectability to vegetation cover. However there is an important difference: there is a particular minimum detection distance — or ‘trigger’ distance — at which the effect begins; at shorter distances topography has no effect. Nor does have topography have any effect if the ground surface along a transect or around a sampling point is more or less level. It will only be important if the landscape is undulating or hilly, and a high proportion of the population is detected further away than the trigger distance (see Figure 21). Often that is not the case.

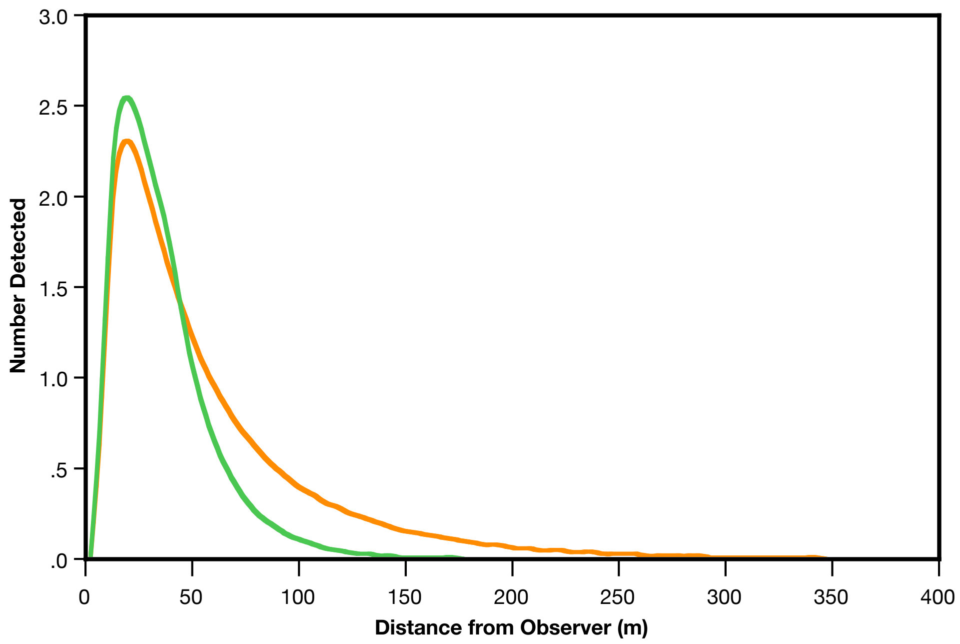


Figure 21. The effect of topography on a frequency distribution of radial distance line transect data. The green line shows how some detection data are distributed in a forested, hilly habitat where observers start to miss animals behind hill crests at about 40m away. The orange line shows how the data would be distributed if the habitat were level and the other main influences (*esp.* population density, vegetation cover) were the same as on the hills.

(The greater number of detections shown by the green line at less than 40m is because there are more individuals available to be detected there, not having been seen at distances where some were hidden by topography.)

To allow for any effects of topography — if you need to — the *WildlifeDensity* program requires only your estimate of the trigger distance for each population. This minimum obscuring distance (d_{tmin}) occurs near the crests of hills (see Figure 22).

To estimate the minimum obscuring distance you have at least two options: (1) make an estimate based on experience, or (2) work from a contour map of your study area to get an estimate based on map information and animal behaviour.

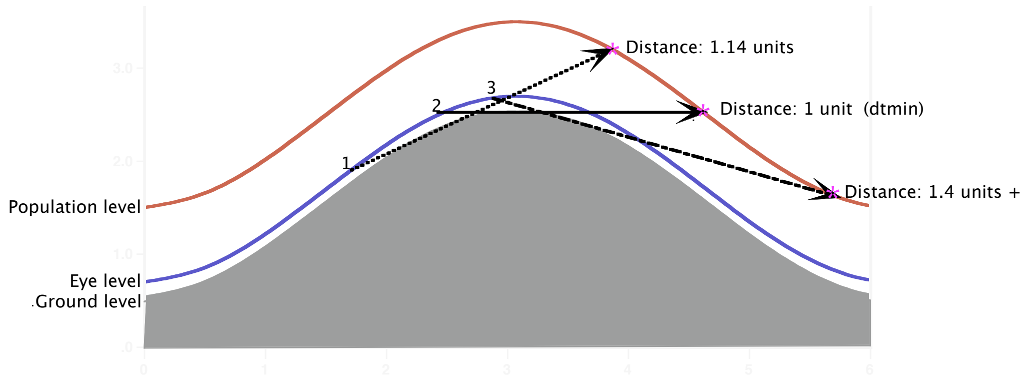


Figure 22. The effect of topography in a relatively simple situation: a rounded crest of a hill or ridge. Observer eyelevel is represented by the blue line, while the median positions of an arboreal animal population are shown by the brown line. Three observer positions are marked, numbered 1, 2 and 3. A line has been drawn from each to the point where an animal starts to drop out of sight behind the ridge top; if further away it would be hidden. The shortest distance at which this happens, d_{tmin}, is shown by the line from Position 2; this 'trigger' distance always occurs near the crest, where the line of sight is horizontal. From any other observer position the distance is greater.

The trigger distance d_{tmin} is thus made up of the observer's distance from the crest, plus the animal's distance from the crest. If observer height to eyelevel is known, and the average animal height above eyelevel also, then this trigger distance can be estimated.

Working from experience. This option is practicable in habitats that are not particularly hilly. In such topography, error on your part will not have much influence on the density estimate. Simply try visualising a typical hill crest in your study area in the way shown in Figure 22 above, then estimate average d_{tmin}. In undulating landscape, values of 50-100m or more are typical while, in more hilly areas, d_{tmin} is often 30-50m.

Calculating a minimum obscuring distance. You can also estimate a minimum obscuring distance sufficiently accurately for density estimation by picturing a typical hilltop as an inverted parabola, with the equation

$$y = -cx^2$$

where y = the height difference between a point below the crest and the crest itself
c = a constant; and
x = the map distance from the crest.

You can work out an approximate value of the constant c in this equation from a contour map of the study area. Look for the steeper ridges and hills, and read the information provided on the map to find

out both the map scale and the distance between adjacent contours. Part of a contour map of the crest of a typical hill is shown in Figure 23.

You can then use this approximation to estimate the minimum topographical obscuring distance.

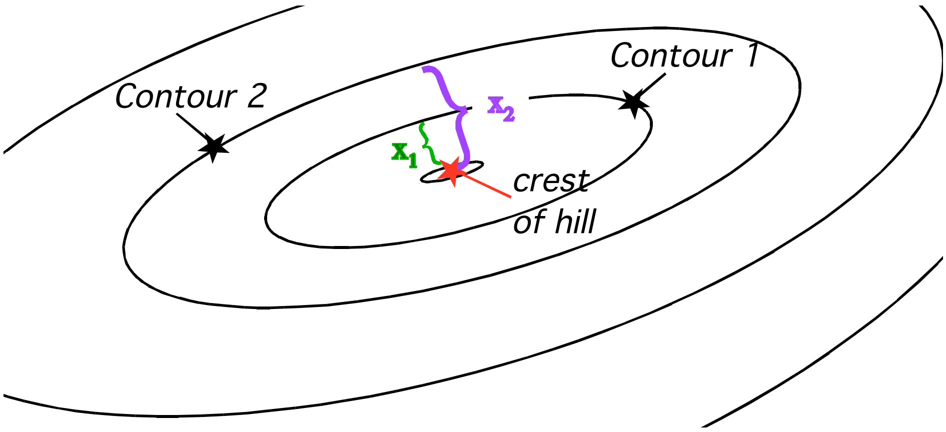


Figure 23. Portion of a contour map with the two contours nearest the crest of a hill marked as 'Contour 1' and 'Contour 2'. x_1 *(in green)* is the shortest distance from the crest to Contour 1, and x_2 *(purple)* the shortest distance from the crest to Contour 2. The two distances x_1 and x_2 need to be measured from the map, and the contour interval $(y_2 - y_1)$ read from the information on the map margin.

◆ *Using Equation 1*:

$$c = \frac{y_2 - y_1}{(x_2 + x_1)(x_2 - x_1)}$$

where	$y2 - y1$	=	the contour interval (in m);
	x_1	=	map distance (in m) from the crest to Contour 1; and
	x_2	=	map distance from the crest to Contour 2.

you can calculate a value for c.

[*E.g.* for a contour interval ($y_2 - y_1$) of 50m, a distance (x_1) of 100m to Contour 1 and a distance (x_2) of 200m to Contour 2, this gives:

$$c = \frac{50}{(200+100)(200-100)} = \frac{50}{300 \times 100} = \frac{50}{30000} = 0.00167$$

]

The minimum obscuring distance d_{tmin} is the horizontal distance x_o from the observer to the crest plus the horizontal distance x_a from the crest to the animal's position in a direct line of sight across the crest. This distance can now be calculated using *Equation 2*.

- *Using Equation 2:*

$$d_{t\min} = x_o + x_a$$
$$= \sqrt{\frac{h_o}{c}} + \sqrt{\frac{h_o + h_a}{c}}$$

where h_o = height of observer eyelevel (in m); and
h_a = average animal height above observer eyelevel

[*E.g.* for an observer height to eyelevel *(h_e)* of 1.5m, and an average animal height *(h_a)* above observer eyelevel of 2m, this gives:

$$d_{t\min} = \sqrt{\frac{h_e}{c}} + \sqrt{\frac{h_e + h_a}{c}} = \sqrt{\frac{1.5}{0.00167}} + \sqrt{\frac{3.5}{0.00167}}$$
$$= \sqrt{898.2} + \sqrt{2095.8} = 30.0 + 45.8 = 75.8$$

To the nearest metre, the estimated minimum obscuring distance is then 76m.]

If you don't know the average animal height above observer eyelevel, but have collected elevation angle data, the *WildlifeDensity* program can be given a preliminary run with (say) a value of 50m for the minimum obscuring distance. The average animal height can be read from the program output. The estimated minimum obscuring distance can then be worked out and the computer program rerun with the calculated trigger value substituted.

Although topography is a highly variable environmental component, experience shows that this approximation — although rudimentary — usually works well enough.

PART THREE :

RUNNING THE PROGRAM

Program Introduction

6

Chapter 6 introduces the installation and operation of *WildlifeDensity*. If you haven't used this program previously, you may like to begin by first printing out and following through the document *WildlifeDensity QuickStart*: *Installation and 'Test-Drive'* that came with the program.

Operating Requirements

Operating system. *WildlifeDensity* is designed to run on Apple Macintosh computers with the OS X operating system installed. Any version from OS 10.4 ('Tiger') to 10.13 ('High Sierra') should work; it may not run successfully on older versions. Because the program carries out a large number of mathematical operations, it runs noticeably faster on more recent computer models with faster processors and abundant RAM.

WildlifeDensity was written for Macs, not Microsoft Windows. If you have only a Microsoft Windows-based computer, you have two options: preferably seek out a relatively recent Mac computer or, if you have some computer expertise, look for virtual solutions to running Macintosh programs on a PC.

Other software. Apart from *WildlifeDensity* itself, you will need one or two other programs, both readily available. The first is a good spreadsheet program to use in collating and organising your field data: either *Microsoft Excel* or Apple's *Numbers* are excellent. Download and install either of these if you don't already have one. Because *WildlifeDensity* outputs its results in text format, you may find it valuable to have a text-based program on the computer, such as *BBEdit* (freeware, downloadable from the Mac App Store or from (http://www.barebones.com/products/); it is free when used as a basic package. The *TextEdit* program supplied with the Mac also works but is more limited.

Installing *WildlifeDensity*

What is provided. The program comes as a disk image file called *WildlifeDensity.dmg,* downloadable from http://biosciences.unimelb.edu.au/research/facilities-equipment-and-resources#Wildlife. Copy the disk image file to the desktop and double-click to open it. It provides:

- Installation *README* (text file)
- *WildlifeDensity QuickStart* — *Installation and Test-Drive* (*.pdf* file)
- *WildlifeDensity*.app (*WildlifeDensity* program)
- *WildlifeDensity* Resources folder, with:

    Techniques Manual & User's Guide (*.pdf*)

Field data sheet templates (all *.pdf*)
Sample Input Data (*WD*, *.dat,* .xls files)

Installing the files. The files are best installed as follows:

1. Drag-and-drop the *WildlifeDensity* folder into the Applications folder on the computer, and the *QuickStart* file to the desktop.

2. Drag the icon of the *WildlifeDensity* file from the Applications folder to the dock on the desktop.

3. If you have installed *TextWrangler*, also drag its icon from the Applications folder to the dock.

4. Drag-and-drop the *WildlifeDensity* Resources folder either into the Application folder with the *WildlifeDensity* program, or into >Library >Application Support, or elsewhere on the computer.

5. Print out the *QuickStart* file.

6. Print out a copy of each of the field data sheets, to use later as templates from which to photocopy data sheets and the recommended fieldwork procedures.

Running a Test

Either run through the procedure from the *QuickStart* file or give the program a short test run, as follows:

1. Navigate to the *WildlifeDensity* Resources folder on your hard drive and locate the Line Transect Radial Example file inside it. Either drag its icon to the *WildlifeDensity* icon in the dock or simply double-click it. A program window should open on the desktop, with the dataset title at the top and five tabs in a line below it. Ignore the rest of the window and select the Estimate tab; this should open the rest of the window below it.

2. Ignore the options there; just click the Calculate button. Data processing should begin. When processing ends there should also be a graph in a separate window. A results summary will also appear in the middle of the main window, together with the locations of two files (*Line Transect Radial Example 1.results* and *Line Transect Radial Example 1.graphData*). These set out the results of the computer run.

3. Examine the graph. The frequency distributions of the original data and the calculated model should both appear on a graph. The data plotted are from a file called <filename>.graphData. The plotted distributions show a typical fit of the model (*continuous line*) to the field data (*dots connected by dashes*). Notice that the model approximates the distribution of the field data. Also observe the characteristic shape of a frequency distribution of radial distance line transect data: a skewed ‘bell curve’ with few or no detections at distances nearest the observer, the number of detections rising to a peak as distances increase, then falling away to zero as distances become even greater.

4. Move the graph window to one side and re-examine the Estimate tabbed window. This time click on the ‘View results’ button to display the contents of the *Line Transect Radial Example.results* file. Look through what it contains. The main item there is the estimated density of the kangaroo population and its standard error (in the table). 95% confidence limits for the density estimate are just

below the table. Notice what else is in the *.results* file: a summary of the main inputs and outputs of the program. Close the .results file.

Fuller information on running the program is in Chapter 9. The next chapter, Chapter 7, deals with data preparation while Chapter 8 deals with setting up an input file.

Support and Feedback

If *WildlifeDensity* is new to you, it may sometimes present problems and difficulties. If you need help or advice, or wish to pass on comments or suggestions, you can email them to wildlife-density@lists.unimelb.edu.au.

Data Collation

7

Overall Procedure

WildlifeDensity is a parametric density estimator based on sampling a fairly uniform survey situation. You should therefore sort your field data into subsets in which visibility is likely to have been fairly constant (*e.g.* forest, woodland, or grassland). Then estimate densities separately for the different subsets. If you don't do this but simply enter all data from a given species into the program, you can get an overall density estimate quite quickly, but it will be less precise and probably less accurate. We suggest first collating and pre-sorting the data beforehand into subsets using spreadsheets, submitting each to *WildlifeDensity*, then examining the results. Final population estimates are only made after that.

You need a spreadsheet program such as *Microsoft Excel* or *Numbers* for collation and pre-sorting. You can then copy and paste observational data directly into *WildlifeDensity.* An alternative is to enter the field data line by line but doing so is slow and tedious.

The main steps needed to obtain population density estimates are listed below and shown in Figure 24. Details follow from p.64 onwards.

1. *Set up a Survey Data File.* Initially enter all relevant field data on a spreadsheet using *Excel, Numbers* or another suitable spreadsheet program.

2. *Sort the Data.* *(a)* Sort the data into sets based on species and number the rows in a new column labelled 'sequence'; *(b)* if the data were collected under very different field conditions (*e.g.* different vegetation), further sort them into subsets that had similar observing conditions (*e.g.* forest, grassland); *(c)* compare the subsets if the survey area is complex and combine any subsets that are similar. Copy each new subset to a separate worksheet or workbook and give it an appropriate name. Reorder the data so the rows are in the original sequence. Spend some time extracting information on subset properties such as section lengths and times spent in each.

3. *Create Data Input Files.* *(a)* For each species and set of observing conditions, open a new *WildlifeDensity* input file and enter its properties under the first two tabs; *(b)* copy the detection data from the relevant worksheet and paste it into the third tabbed window. Save each *WildlifeDensity* input file.

4. *Run the Program.* Open each *WildlifeDensity* data input file and run the program; examine the output graph to see how well the model fits the data; if necessary, modify the initial parameters and rerun the program. Examine and save the final results.

THE MAIN STEPS IN DATA PROCESSING

Step 1: enter all field data into a spreadsheet; number the rows sequentially

Step 2a: sort the data into initial subsets based on species, then habitat type (and other factors if warranted).

Step 2b: transform all detection distances to logarithms; for each species, compare the transformed distance data to identify similar and different subsets.

Step 2c: rearrange the data into new sets based on species and different detection distance classes; re-order each in the original sequence.

Step 3a: save each new data set as a separate spreadsheet file, with detection data in adjacent columns in the sequence: distance - number - horizontal angle - elevation as present.

Step 3b: For each data set: open *WildlifeDensity*, enter the method and sample details, then cut-and-paste the observational data; set the run options and check for errors.

Step 4: For each data set: run *WildlifeDensity*, then examine the output graph to see if the program has found an acceptable minimum; if not, revise the search options and re-run. Examine (and print) the results.

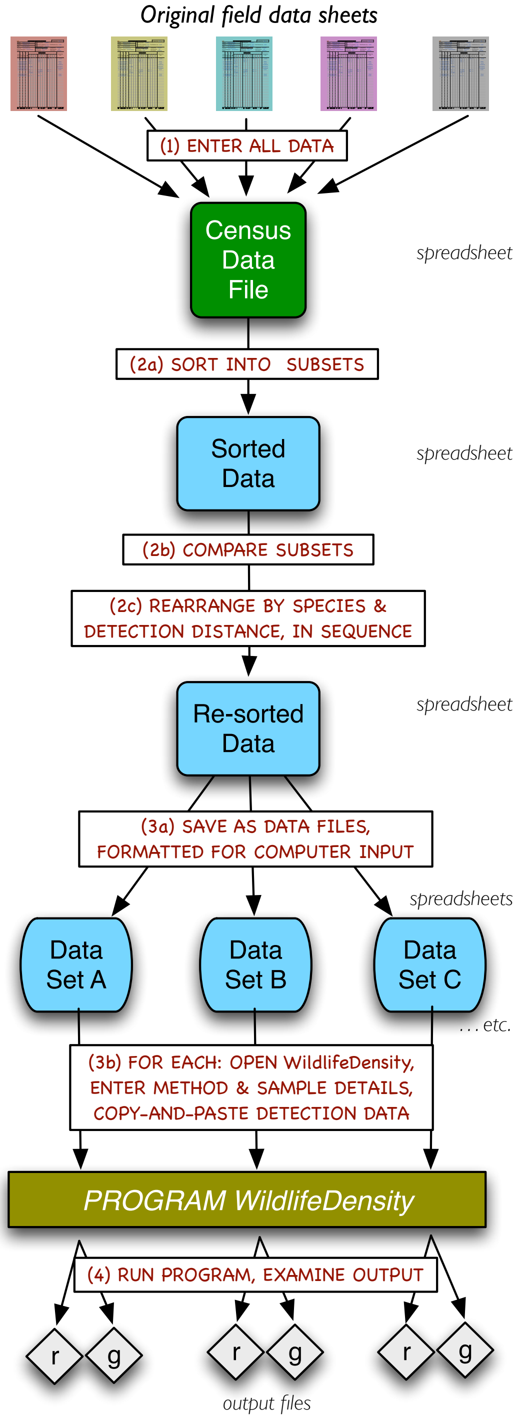


Figure 24. The main steps in deriving population estimates using *WildlifeDensity*. Details are set out in the text. A final steps is to combine the estimates from individual data sets by using stratification method.

5. *Calculate Overall Population Estimates.* As needed, combine those results to obtain an overall density or local population estimate for the species and survey concerned.

Setting up a Survey Data File

The first step in processing field data is to enter them into a program with suitable formatting and processing options. We will assume you have a recent version of *Microsoft Excel*, perhaps the most widely-used program of its type at present, or Apple's *Numbers*. Both have a spreadsheet format (with rows and columns) and useful ways of sorting and processing data. The account below is based on *Excel* and set out in detail to help users doing this for the first time.

Filenames and survey codes. Open a new *Excel* workbook and save it with a filename that identifies its contents. *E.g.*: Black_Range_Jul2016.xls A specific survey code that can appear within the file can also be useful, such as one that indicates both survey date and location *E.g.*: 1607BLKRA (*i.e.* 2016, July, Black Range).

Spreadsheet layout. Because data have to be transferred from field data sheets to the survey data file, and subsequently to input files, use a layout that simplifies the task and minimises copying errors. The layout suggested below is based on the sample line transect and fixed point data sheets provided with *WildlifeDensity*, with some modifications to suit the sorting task.

COLUMNS:

Shortened column title suggestions for the spreadsheet are set out below in left-to-right *Excel* column order, with sample data entries. You can format each column as needed.

(A) Sequence: row number of the data when first entered, to make it easy to rearrange the file in its original sequence after sorting. *E.g.* [Row] 132

(B) Survey: a survey identifier. *E.g.* 1607BLKRA

(C) Tr_nmbr: the transect or fixed observing point number *E.g.* 07

(D) Tr_lngth: overall length of a transect (usually in metres; leave column blank if fixed point). *E.g.* 3450

(E] Tr_dirn: overall transect compass direction, in degrees (if transect is straight; otherwise left blank). *E.g.* 238

[F) Obsrvr: either the observer's name or a suitable code such as their initials or an identification number. *E.g.* RWH, or 216

(G) Species: a code which shortens the species name to a few letters to save space but to be instantly recognisable to the user. *E.g.* EGK for eastern grey kangaroo, PFN for peregrine falcon

(H) Cld_cvr: the average cloud cover at the time of sampling. *E.g.* 6/8, or 75 (%)

(I) Prcptn: type of precipitation (if any), and its intensity. *E.g.* 0, or steady light rain, or occasional hail (or your own codes for precipitation types)

(J) Temp: the temperature range during sampling. *E.g.* 16-18°C

(K) Wind_dirn: the approximate wind direction. *E.g.* NNW

(L) Wnd_spd: the overall wind speed, on a recognised scale if possible. *E.g.* Beaufort 2-4, 10-15 km/h, 5-15 kn

(M) Sample: the individual sample code, such as a section number from a line transect, or the sampling point code from a fixed point survey. *E.g.* W04

(N) Start: the transect section or fixed point count starting time, in 24h clock format. *E.g.* 14:23

(O) Finish: the transect section or fixed point count finishing time, in 24h clock format. *E.g.* 14:53

(P) Duration: the duration of the sampling period, in minutes *E.g.* 30

(Q) Scn_lgth: the approximate length of a transect section, usually in metres. *E.g.* 247.6 [usually not entered initially, but calculated later]

(R) Bearing: for each field observation, the compass direction from the observer to the detection point. *E.g.* 247 [perpendicular distance transects only; otherwise left blank]

(S) Distance: for each observation, the horizontal distance from observer to detection point, in metres or (rarely) kilometres. *E.g.* 122 [Set at 0 if an overtake]

(T) Number: for each observation, the number of individuals detected in the group. *E.g.* 3

(U) Hor_angl: the horizontal lateral angle between the transect compass direction and the bearing to the detection point. *E.g.* 9 [calculated later]

(V) Elevatn: the angle of elevation above (+) or below (-) eye-level to the detection point (if measured; otherwise left blank). *E.g.* 12 or -2

(W) Habitat: the principal habitat type within a transect section or surrounding a sampling point, usually in a code form. *E.g.* F (forest)

ROWS:

Enter all column titles along the first row of the spreadsheet from Columns A to W of the spreadsheet. After that, for each new datum (transect section, sampling point or additional observation), start a new row. Every sample will have at least one row of data even if no observations were made, and more than one row if there were two or more observations in the sample (one row per observation).

1. Sort your original field data sheets into a convenient sequence ready for data entry. *E.g.* according to sample number or date-and-time order.

2. Enter the first row of data for a sample. Begin by giving the line a sequence number in Column A. Numbers in successive rows can then initially be in consecutive order from top to bottom of the spreadsheet, preferably to indicate the original observation sequence. (At first the sequence number will be one unit higher than the row above it in the spreadsheet, though this will cease to be true once data sorting begins).

Copy the data from the field data sheet into the appropriate columns along the row. Leave irrelevant spreadsheet columns blank (*e.g.* the Bearing column with radial distance or fixed point data); also leave the Scn_lgth and Hor_angl columns blank at this stage (both can be completed

later). If you already know section lengths from direct measurements (*e.g.* with permanent transects) enter them now.

If you are entering line transect data, and have any *Distance=0* values that are actual detection distances and not overtakes, enter these distances as '0.01' to distinguish them from overtakes (which are recognised by being exactly 0). Don't be concerned about doing this: recording a distance as 0.01 instead of 0 has negligible effect on results. With detection distances, avoid using negative numbers.

3. Enter subsequent rows for a sample. If there was more than one observation (detection) within a transect section or at a fixed point, start a new row for each separate observation. For these additional rows, do not enter data in the Tr_lngth, Duration, or Scn_lgth columns, which you should leave blank. (You can use *Excel's* Edit>Fill>Down command to enter data in many of the other columns.)

Begin a new row for every additional observation and every new sample (transect section or sampling point). Continue until all sample data have been entered.

4. Calculate lateral detection angles. If you are making radial distance or fixed point density estimates, you do not need lateral angles. If you wish to use perpendicular distances from a transect line to estimate densities, you will need lateral detection angles in the Hor_angl column (Column U), unless you have calculated the perpendicular distances beforehand (when you leave Column U blank).

5. Calculate perpendicular distances. [If you need perpendicular distances, first subtract Bearing (Column T) from Tr_drn (Column E) by entering a formula in the Hor_angl column of Row 2. (The *Excel* formula is ' **=E2-R2** ' if you are following the suggested format.) Press Return. Then select the cell that contains the formula, drag down to the end of the column, then choose Edit>Fill>Down. A lateral angle should appear for each observation in the data set other than overtakes.] Some angles will be positive, some negative and some close to North may have unexpected values (*e.g.* 372°, -8°); do not worry about these—*WildlifeDensity* allows for them. Rows without observations will have zeroes in the Hor_angl column; these can be deleted for tidiness' sake if you so wish.

6. Total times spent and distances travelled. Total the Tr_lngth and Duration columns.

[To do this, enter the formula ' =sum(Crt : Crb) ' (where C is the column identifier, rt the row number of the top cell and rb the row number of the bottom cell in the spreadsheet column) either in a cell below the 'Tr_lngth' column or on the spreadsheet to the right of your data: *e.g.* '**=sum(C2:C205)**'. Press Return. Do the same for the Duration column.]

Record the total time spent in minutes and the total transect length (if applicable) in metres. If you subdivide transects into subsets, you will need to do this for each of these as well at an appropriate time.

7. Calculate section lengths. If you need to estimate individual section lengths to complete line transect data entry, this can usually be done sufficiently accurately by assuming that observers travelled at more-or-less even overall walking speeds during the transect, then use time spent on a section to estimate section length. Alternatively, if you actually measured the section lengths (*e.g.* with a pedometer or via GPS), you could enter those measurements.

[To estimate section lengths from travel speeds using *Excel*, enter the formula '**=P2*(total transect length)/(total transect duration)**' into Column Q, Row 2, using the totals just calculated. Press Return. Then select that cell, drag down to the bottom of the spreadsheet to select the full column,

then choose the Edit>Fill>Down command. You should now have one section length estimate per section, with zeroes where there are additional rows for a section; you can delete the zeroes if you so wish.] If you wish, work out the observer's overall rate pf travel, in m/min.

This completes initial data entry. Check over the completed file for possible copying errors, and ensure that no key data have either been omitted or miscalculated. (Unless you are an unusual person there will usually be some copying errors.) Once you are satisfied the data are accurately transcribed, save and backup the survey data file.

Sorting the Data into Sets

The *WildlifeDensity* model assumes that data were collected under relatively uniform observing conditions. For best results, you should collate (collect and combine) all field data of each species into sets collected under similar observing conditions before you submit them to the program. This always involves first subdividing the data into species-based sets, but you may have to further subdivide each species' data into subsets that differ significantly in visibility as a result of differences in lateral vegetation cover and, occasionally, in weather conditions or observer characteristics. Dissimilarities should show up as significant differences in detection distance distributions under the different observing conditions. Although you can sometimes achieve relatively accurate density estimates without subdividing data in this way, doing so usually improves precision.

If you suspect that vegetation cover, weather conditions or observer differences may have significantly affected detection distances, investigate possible differences before you create input files for the computer. The following procedure usually works well:

1. Create a file for sorted data. Duplicate the original spreadsheet file and give it an appropriate new name, such as *Sorted_<surveycode>_Data.xls*.

2. Sort the data. In *Excel*, spreadsheet files can be sorted into subsets based on selected properties. The Sort command in the Data menu can re-sequence the rows using several criteria at a time, such as the names in the header row or the column code. Try sorting the survey data file first by Species, then by Habitat. You can further sort by a specific weather factor (*e.g.* light winds/ high winds) or by Obsrvr if you suspect any significant effect of either. The sorted data will then occupy different groups of rows in the spreadsheet; you can select and rearrange or copy these as needed. (They are easier to work with if you insert blank rows between each subset of sorted data.)

You now need to find out whether or not the habitat (and perhaps weather or observer factors as well) is having a significant effect on detection distances. If it is not, sorting by that factor is unnecessary.

3. Compare detectabilities. You can use standard statistical methods to compare the detection distances of the species of interest (see recognised statistical programs and textbooks). Because small detectability differences have relatively little effect on density estimates, simple statistical tests seem adequate for most survey data. For each sorted set, the procedure below is usually sufficient. If the distribution of data is approximately normal (Gaussian), doing this produces usable statistical measures.

Because many sets of detection distances are highly right-skewed, you can roughly normalise the distributions by transforming detection distances to their logarithms before comparing them. Then calculate the means and standard deviations of each transformed set and compare them (*e.g.* graphically—*see Figure 25*). This is usually sufficient to show if there are differences between data collected under different conditions. In *Excel* you can do this as follows:

(a) Make a new column on the spreadsheet (with a heading Log_dist);

(b) Write the *Excel* formula '=log10(R2+1)' in Row 2 of this column and press Return;

(c) Select the rest of the column by dragging down from this cell to the bottom of the column;

(d) Choose Edit>Fill>Down (when the logarithm should appear in each cell in the column);

(e) Re-sort the rows you have chosen based on Log-dist: you are to omit the zero values (overtakes) from the next step);

(f) Select Tools>Data Analysis>Descriptive Statistics from the *Excel* menu bar. (Load the Data Analysis Tools first if you need to.) Select all Log-dist values above 0 as your Input range. Request 'Summary statistics'. Decide where you want the output printed using the Output options, then click 'OK' and examine the output.

(g) Repeat for each subset of your data, and record the mean and standard error of each subset of transformed data. Graph the results if you wish (*see Figure 25*), then save the file and keep it open.

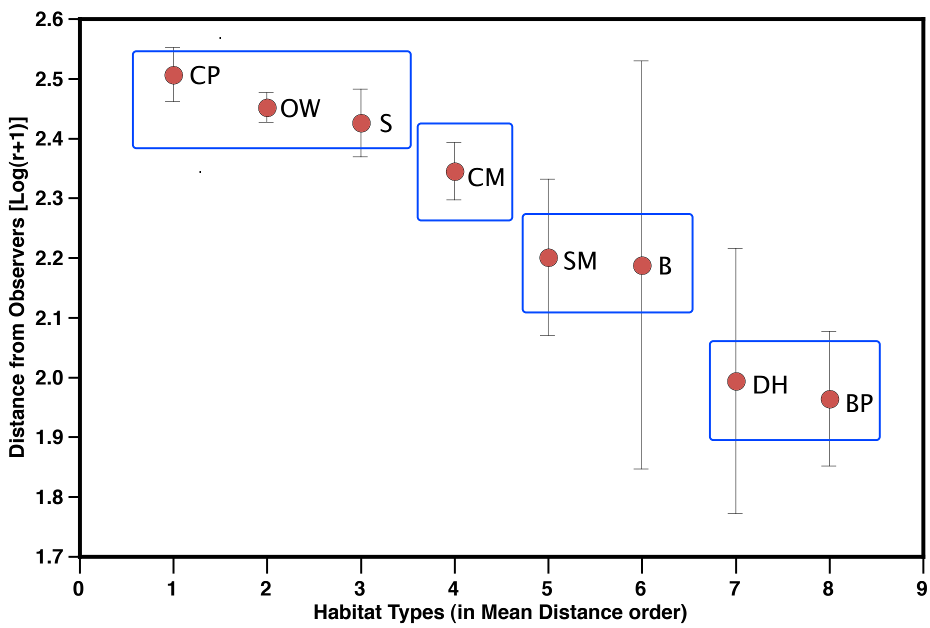


Figure 25. A graph of the means (dots) and standard errors (bars) of log-transformed detection distance data on a kangaroo population from 8 different habitat types in the same general locality. The longer bars were based on small numbers of observations. Based on the distributions shown in this graph, the data were grouped for computer analysis into 4 sets with similar detection distances (CP+OW+S, CM, SM+B, DH+BP). This grouping matched observer

perceptions: CP, OW and S were open, almost treeless areas; DH and BP were relatively dense woodlands; CM, SM and B had intermediate vegetation cover.

4. Regroup data into similar sets. For each species of interest, use cutting and pasting to group together all the data collected under similar detectability conditions, including any zero values. Doing this usually produces several subsets from a given locality (*e.g*. 3) per species. Select each set in turn and copy it into a separate worksheet in the Excel data file. Label the tab for each worksheet appropriately. Save the file but keep it open.

5. Check your data. In each worksheet, scan down the columns to check for inadequacies or errors in the data. Particularly: (a) look for any missing values in a row; and (b) if elevation data are supplied, check that no elevations of exactly 90˚ have been included; if there are some, reset them as a slightly lower angle, e.g. 89˚, to avoid any computational problems.

6. Reformat the data subsets. In the first worksheet of sorted survey data —

(a) Re-sort the rows using Sequence as the basis; this produces a spreadsheet in the same sequence as the original data file. *(b)* Total and record the entries in the Duration and Scn_lgth columns. *(c)* Repeat for each subset.

7. Prepare each subset for computer input:

(a) Because *WildlifeDensity* needs the distance data in the first column under the Observations tab, in the first worksheet check that the columns with the detection data (S, T, U and V) are in this sequence: Detection distance | Number in group | Lateral detection angle | Angle of elevation. Rearrange by cutting and pasting if necessary.

(b) Repeat with each worksheet data set in turn. Save and close the file, with an appropriate name, preferably as comma-separated values (with a *.csv* suffix), though ordinary *Excel* and *Numbers* files are also usable.

You should now have your original observational data in a form suitable for copying to data input files. How to create each computer input file is described in the Chapter 8: Data Entry.

Data Entry

8

How the Program Works

WildlifeDensity compares the frequency distribution of your data with a mathematical model designed to fit the detection distance distribution closely. The fitting is done iteratively. The model then estimates the population density and values of shape parameters that best fit the data.

Data input. The program needs the survey data and an appropriate class interval for the detection distance before it will run. Initial values to start a search for 'best fit' model parameters can be estimated automatically or supplied by the user.

A first set of iterations. The program begins by dividing the data into distance classes and totalling the number of visual detection events in each. It then uses its internal models to calculate the expected number of such events in each class. Given initial values of the key parameters, It compares calculated and observed numbers in each class, then squares and totals the differences between them. The program next changes one of the parameter by a predetermined amount and calculates a new total difference value. It repeats the procedure with a second parameter, and so on. Difference values are then compared with the centre-point of a cluster of such values in a step-by-step mathematical procedure (the downhill simplex method) designed to reduce the overall difference between the observed and calculated values. This process continues until a minimum difference is reached, when computations stop. This completes the initial set of iterations. The first search for a minimum is complete and the 'best value' of each parameter is retained.

Subsequent iterations. The program then randomly resamples the original data with replacement ('bootstrapping'), and repeats the entire process to produce a second set of best values, then a third set, then a fourth and so on up to a limit set by the user (see **Number of sets of iterations** below). The parameter values reported in the program output are the means and standard errors of the best values from the individual sets of iterations.

Setting up the Data Input File

The process begins with data entry. *Enter your data in the order given below.*

Opening *WildlifeDensity*. Open the program either by clicking on its icon in the dock or opening it from the Applications folder of your computer. A window will open named 'Untitled', with a 'Data Set Description' panel at the top, five tabs below it with labels from 'Method' to 'Estimate', and a set of radio buttons and panels below that. It usually opens at the Method tab.

Filename. Click in the ***Data Set*** **panel** and type in an identification name for the file that contains a brief description of the data set. [*E.g.*: **Run18104: Red-necked Wallaby, Black Ra. forest, Jul18.**]

Save the file, giving it a suitable identrfication [e.g. Run18104].

Method tab (Click the Method tab if it is not visible)

◆ ***Census type:*** Select the button that indicates the type of survey data. The **Distances supplied as** options will be greyed out unless you select the perpendicular distances button; if you do, choose the button that indicates whether •you are supplying *radial distances and lateral angles* for each observation or •are supplying *pre-calculated perpendicular distances* instead.

◆ ***Observation type:*** Select the appropriate button (usually the first). The **auditory data** option is rarely used — it is intended only for use with detection distances based on sound alone (*e.g.* frog populations) or for use with populations seen at very considerable distances where vegetation is absent (e.g. surfacing whales detected over the sea under misty conditions). The third option is for use with data within a *range* of distances only (such as strips of vegetation bordering many country roads). To enter these, select **visual data, distance range limited** and type in the distances to the inner and outer boundaries of the data range [e.g.: 0 250] The minimum radial or perpendicular distance is usually 0 unless for some reason detections very close to the observer or on the transect line are to be disregarded. For example, small minimum distances (*e.g.* <5 or <10m) may be sometimes be appropriate, as for a transect along a road or pathway.

◆ ***Transect length:*** Enter the total transect length travelled when collecting data [*e.g.:* 34524.5]. Select the distance unit, in m or km. Also choose the button that indicates whether data came from **one side** or **both sides** of the transect line

◆ ***Detection distance unit:*** This will be greyed out unless the transect length is entered in kilometres. If so, select the appropriate detection distance unit.

Click the ***Sample Details*** tab to open the next window.

Sample details tab

◆ ***Time spent:*** In the first panel, enter the total time spent collecting the data set being entered here, expressed in minutes [*e.g.:* 3496].

◆ ***Population movement rate:*** Enter the average horizontal displacement of an individual animal during the survey period, expressed in metres per minute [e.g.: 22]. This either comes from previous behavioural studies or is an estimate. If the population is relatively sedentary compared to the observer's rate of travel, the rate need only be approximate.

As set out in Chapter 5, the population movement rate is the average horizontal displacement (travelling speed) of an individual animal when it moves from place to place, multiplied by the average proportion of its time spent moving. Population movement rates seem to depend very much on the foraging methods of the species involved and characteristics of its foraging sites. If you are happy to enter an approximation, Table 2 on the next page provides data on representative species as a guide.

Identify the appropriate category for your species and use the suggested movement rate for that category. This should be adequate for most line transect surveys, especially for relatively sedentary species that have movement rates less than the observer's rate of travel. However, for line transect surveys of active species that have movement rates faster than the observer's, and for all fixed point surveys, use a movement rate based on actual field data (*see Ch.5*). Enter an appropriate rate, expressed in m/min.

Table 2. Approximate overall movement rates (travelling speed x time spent moving) in typical bird and mammal species, expressed in m/min. Their overall rates have been grouped into seven categories based on feeding methods and use of foraging sites. A representative rate for each category is shown in bold type.

	Species and Foraging Method	**Rate (m/min)**
1	* slow-moving (usually larger) herbivorous mammals that graze on the ground or browse in or on trees and shrubs * larger, slow-moving birds that stand on the ground or perch motionless looking for invertebrate prey or small vertebrates	under 5 **(2.5)**
2	* continually-moving grazing and browsing mammals (mainly the smaller herbivores) * larger seed-eating birds that mostly forage on the ground (*e.g.* pigeons) * small birds that glean insects from the ground, fallen timber and low vegetation, or drop on prey after long waits at a low vantage point	5 - 12 **(8.5)**
3	* largely seed-eating birds that forage both on the ground and in foliage (*e.g.* finches, parrots) * relatively slow-moving insectivorous birds that move about on the ground and/or in foliage, moving on to a new site occasionally (*e.g.* magpie-lark, pardalotes)	12 - 18 **(15)**
4	* active bird species that move about continually, often in small flocks, searching for food items in the foliage of trees and shrubs, or by flying from trees and shrubs to the ground and back * typical nectar-feeding birds of foliage that feed for a time in a tree, then move on to the next	18 - 25 **(22)**
5	* very active nectar-feeding and insectivorous birds that move about continually, and also fly in the air for short periods to hawk flying insects or glean prey from surfaces while in flight	25 - 50 **(38)**
6 a	* birds that feed largely by hawking flying insects, but do so from vantage points amongst trees (*e.g.* typical flycatchers, fantails, wood-swallows)	50 - 100 **(85)**
6 b	* birds that spend much of their time in flight over open ground, often in flocks (*e.g.* swallows, swifts)	100-200 **(150)**

◆ ***Proportion of observing arc scanned:*** This is needed for fixed point data only. Enter the proportion of a circle centred on the observer being scanned. If the observer rotates more or less continually, an arc of 360° is scanned. If scanning covers less than that, and the arc scanned is

expressed in degrees, its portion must be converted to a proportion between 0 and 1. (*E.g.* a 180° scan gives a proportion of 180/360 = 0.5.) If your data are from fixed points, enter the relevant proportion; if from transects, leave its value at 0.

◆ ***Elevations:*** If the population is dispersed well above or below observer eyelevel, and elevation angles are supplied in the data set, select ***Elevation angles supplied***. If you don't have angle data for the observations, enter (in m) the approximate height difference between observer eyelevel and the population's height above ground. If you have elevation angle data for your observations, enter them later under the **Observations** tab and select ***Elevation angles supplied*** now. You can also enter the root mean square height difference between them in the panel at ***Population elevation difference approximately.*** If the height differences are relatively small [*e.g.* 2 m or less], a rough approximation is enough. Finally, if you have some elevation angle data, but your data set is incomplete, you can calculate the ***root mean square height difference*** in metres and enter that here. It is $\sqrt{(h_1^2 + h_2^2 + h_3^2 \ldots) / n}$, where *h* is the height difference and *n* the number of measurements made.

◆ ***Topography:*** If topography in the survey area is approximately level, or most animals in the population are too close to the observer to be hidden behind a hill, select ***Topography approximately level.*** If the ground surface is undulating or hilly and some distant individuals could be out of sight, select ***Topography undulating, obscures some wildlife*** and enter the approximate average minimum distance from the observer (to the nearest 10m) at which the target species starts to drop from view behind a ridge or hilltop *(see Chapter 5).*

◆ ***Proportion of the population observable:*** This is a special-case variable used only where part of the population is hidden from an observer, as can happen if some individuals are sheltering in underground burrows (*e.g.* the European rabbit), in tree hollows, or a nest. Express the proportion as a value between 0 and 1 [*e.g.* 0.85]; for most populations at most survey times the proportion observable will be 1.

Click on the ***Observations*** tab to open the next window.

Observations tab

This window is for the detection distance data. There are two ways you can enter data: by copy-and-paste from data file spreadsheets or by direct entry, one observation at a time. Try the copy-and-paste option—it's much faster and less prone to copying errors.

◆ ***Copy-and-paste method.*** Begin with field data collated on *Excel* or similar spreadsheets, as described in Chapter 7. ***Distance, Group Size, Horizontal Angle*** and ***Angle of Elevation*** should be side-by-side in Columns S-V of your data file worksheets, in that order, if you follow the recommended procedure. You need to fill in two, three or four columns depending on your data. Whatever data you supply, make sure the columns are in that sequence from left to right.

1. **Important:** Do not enter any data in this window unless you have first entered the survey details in the **Method** and **Sample Details** windows because doing so sets up the columns. The Observations window should then show the appropriate column headings in the correct order.

2. Open your survey data file, then the appropriate worksheet. Select and copy (Edit>Copy, or ⌘-C) the relevant data columns (but *not* the column headings). The 2-4 columns should be in the order *Detection distance* | *Number in group* | *Lateral detection angle* | *Angle of elevation.* Don't be concerned if there are blank rows or columns; they don't affect computation and can be left in. But check there are no single blanks; if so, delete them by first selecting them then using the '-' button.

3. If you are entering perpendicular distance detection data and the population concerned is an actively mobile one, you need to know that the *WildlifeDensity* program treats a '0' value in the *Detection distance* column as an overtake. Double check all zero entries in the distance column against your field data to see whether an individual '0' entry means 'zero distance from the transect line' or 'overtaking the observer from behind'. If it means 'zero distance', then alter the '0' to '0.01' or a similar very small distance in m. Doing that stops it being identified as an overtake but has a negligible effect on the density estimates.

4. Open the **Observations** window and select Edit>Paste (⌘-V). Your data should then appear in the appropriate columns.

5. Save the program file, using the file number you chose earlier [e.g. Run18104]. The file name should appear at the top of the window with the extension .WDdata, and usually the *WildlifeDensity* icon as well.

   You can amend the entry in any cell if you select the cell first by double-clicking it, then retyping its contents You can also copy, cut and paste the contents of an individual cell provided you first select it by double-clicking. You can use Select All (⌘-A) to get all the cells to respond together (e.g. if you wish to delete all the entries in the table).

◆ ***Direct Data Entry Method.*** You can also enter observational data directly into the Observations window, one detection at a time. This is relatively quick and easy with a small data set, but tedious with a large one. This is the procedure:

1. Check that you have entered the survey details in the **Method** and **Sample Details** windows. The **Observations** window should then show the appropriate number of columns and column headings.

2. Click on the '+' button at the bottom of the window, then double-click the number in the first cell where you are to enter data. Type in the relevant number. Repeat for the next cell, and so on.

3. Repeat for the next row. Continue until all data are entered.

4. Check the accuracy of entries, and correct any errors.

5. Save the file, using the file number you chose earlier [e.g. Run18104]. The file name should appear at the top of the window with the extension *.WDdata*, and usually the *WildlifeDensity* icon as well.

You can use the '+' and '-' buttons to add or delete whole rows.

[You can amend the entry in any cell if you select the cell first by double-clicking it, then retyping its contents You can also copy, cut and paste the contents of an individual cell provided you first select it by double-clicking. You can use Select All (⌘-A) to get all the cells to respond together.]

Click on the ***Options*** tab to open the next window.

Options tab

◆ ***Class interval for calculations.*** Enter an appropriate class interval (or 'bin') width to be used in program computations and output results files, measured in metres and preferably to at least one decimal place (*e.g.* 7.3). Doing so alters the number of detections in each class. This changes the density estimate somewhat, especially if there are few detections and few classes (and can also reduce the impact of any 'heaping' errors in trhe data). You need to choose a width that works well with your data.

To decide a suitable bin width:

1. Identify the ***maximum*** and ***minimum*** detection distances in your sample. (With perpendicular distance data the minimum distance will be close to 0.)
2. Subtract the minimum from the maximum to give the ***range*** of distances.
3. Total the number of ***groups*** detected (not the total individuals).
4. With radial distance or fixed point data, calculate your bin width as

$$\textbf{r\_interval} = 0.048 \times \textbf{r\_range} - 0.01 \times \textbf{groups} + 3.5$$

5. With perpendicular distance data where you have the radial distances available,

$$\textbf{y\_interval} = 2 \times [\, 0.048 \times \textbf{r\_range} - 0.01 \times \textbf{groups} + 3.5 \,]$$

6. With perpendicular data when you only have pre-calculated perpendicular distances,

$$\textbf{y\_interval} = 0.08 \times \textbf{y\_range} + 3.4$$

You can also use other bases for your decision; the approach here is known to work well. Know that the minimum width allowed by the program is 1/80 times the maximum detection distance. If you try to set a smaller interval, the program will automatically reset it to 1/80 of the maximum detection distance.

◆ ***Number of iteration sets:*** Enter the number of sets of bootstrapped data to be computed by the program when estimating the population density and other parameters. Suitable values are 250 sets of iterations for a good approximation, 500 for a 'best estimate', 750 for serious work based on a large data set, and 1500 for a 'best' answer. Additional iterations usually improve the estimate but take a little longer to complete.

[You can also run the program without bootstrapping by setting the number of iterations at 1. This initiates a quadraric surface fitting procedure within the program. Although computation can then be very rapid, the method is less dependable, the output is less, density estimates may be slightly biased and standard errors low *(see* Chapter 8*).*]

◆ ***Initial parameter values and options:*** *WildlifeDensity 2* provides automatic selection of initial parameter values and step sizes as a built-in default. We recommend this.

[You need to know that you must use manual selection if you decide to set upper or lower limits to the range of detection distances or parameter estimates may be biased. To disallow automatic selection, or to display progress in parameter estimation, select the **Select initial values and options manually** button, also select the 'Tabulate' button under the options and follow the procedure described under **Manual selection option** on p.77.]

◆ ***Verbosity and debugging options.*** Selecting any of these buttons provides you with additional technical output on the computation process. The output is then included within the .results file. *Warning:* the output can from the upper two options can be considerable, potentially producing some very large output files. Details are in Chapter 10. For most computer runs, leave these buttons unselected.

Unless you decide to use the manual selection option, go directly to ***Very small samples*** on p. 80.

Manual selection *(usually optional)*

If you decide to use manual parameter selection, proceed as follows.

For each parameter used by the model, you need to enter an **initial estimate** to use in the first computation, and a **step size** to begin altering the parameter in later iterations. The initial values can be properties of the observing situation you already know, such as measured lateral vegetation cover, or estimates of those parameters from previous computer runs. It is important that these are well chosen: if they are very inaccurate, the program may fail in its search for a minimum difference between observed and calculated frequencies.

Setting any step size at '0' fixes the parameter at its initial value for all calculations.

Four parameters are used in the *WildlifeDensity* program. The first two are ***shape parameters,*** determining the shape of the frequency distribution curve, *viz.*:

Conspicuousness coefficient. The ***initial estimate*** is an approximation to the conspicuousness of the target species to an observer, expressed in metres.

You can estimate its value by picturing how many metres from you an individual animal would have to be for you, under the census conditions, for you to just begin to overlook the occasional animal if it's stationary, quiet and partly hidden. Typical values are about 20m for a relatively large animal (*e.g.* cattle, an emu), about 15m for a medium-sized animal (*e.g.* a kangaroo or deer), ±10m for a larger passerine bird species, ±8m for an active, smaller songbird, ±5m for a cryptic species and as little as 3m for highly cryptic species (*e.g.* stationary quail amongst dense grass). Table 3 (*next page*) gives typical values. If you already know a typical value from previous analyses, use that.

If uncertain, make your estimate higher rather than lower than the suggestion made.

A workable ***step size*** for the conspicuousness coefficient is about a third of the initial estimate [*e.g.* a step size of 6 to accompany an initial estimate of 18]. If you don't do this, *WildlifeDensity* will preset the parameter value for you using a number it calculates from the original data.

Lateral cover. Lateral cover is the average amount of vegetation (tree-trunks, branches, foliage) in a direct line between observer and an animal, potentially hiding the animal from view. For visual data from foggy conditions in the open, or for auditory data, this parameter is the current attenuation coefficient in air for the transmitted visual or auditory signal.]

Lateral cover is measured as a proportion of the line-of-sight obscured. Its value is a dimensionless number (no unit) always appreciably less than 1 [*e.g.* 0.005]. Typical values are shown in Table 4 (p.79). Again, if in doubt, err on the high side.

Enter the same value for *step size* [*e.g.* 0.005].

Table 3. Estimates of the conspicuousness coefficient and maximum recognition distance (rounded) returned by *WildlifeDensity* for a variety of (Australian) mammal and bird species, and probably appropriate for other, similar populations. Notice the relationships between size, behaviour and conspicuousness. The bracketed value in the third column is a suggested initial value for data entry.

Species	***Properties***	***Conspicuousness Coefficient***	***Maximum Recognition Distance (m)***
emu	1.5 - 2 m; flightless	18 **(20)**	3500
eastern grey kangaroo	30 - 70 kg	14 - 21 **(16)**	2400
western grey kangaroo	25 - 55 kg	11 - 20 **(15)**	1800
koala	7 - 14 kg	8 - 12 **(10)**	300
common brushtail possum	1.5 - 4 kg	4 - 6 **(5)**	150
white-browed wood-swallow	17 cm; aerial, noisy	42 - 44 **(40)**	160
green rosella	32-38 cm	14.4 **(15)**	150
swift parrot	23-26 cm	16.4 **(15)**	190
yellow wattlebird	37-45 cm	13 **(15)**	170
red wattlebird	33-36 cm	12-13 **(15)**	200
noisy miner	24-27 cm	11 **(10)**	170
helmeted honeyeater	17-22 cm	5 - 16 **(10)**	160
spiny-cheeked honeyeater	22-26 cm	6 - 10 **(10)**	170
common starling	21 cm	9.3 **(10)**	210
yellow-plumed honeyeater	13 - 16 cm	4.8 - 5.2 **(5)**	110
weebill	8 - 9 cm	4 - 6.5 **(5)**	100
striated pardalote	9.5 - 11.5 cm	3.5 - 4.8 **(5)**	80
grassland quail	12 - 22 cm	1 - 5 **(3)**	30

Table 4. Some values of the lateral vegetation cover returned by *WildlifeDensity* for bird and mammal species in a variety of Australian vegetation. Species that forage within foliage usually have greater cover than those that forage elsewhere. Bracketed values in the last column are suggested initial values for lateral vegetation cover.

Habitat Type	***Species***	***Lateral Vegetation Cover***
grassland, very open woodland, dry lake beds	ground-feeding species (*e.g.* kangaroos, emus)	0.000 **(0.000)**
shrublands, open woodlands	ground-foraging mammals and birds	.003 - .008 **(0.005)**
parks, woodlands	ground-foraging mammals, birds	.010 - .011 **(0.010)**
woodlands, tall shrublands (*e.g.* mallee)	arboreal mammals (*e.g.* possums) and larger tree-foraging birds	.013 - .018 **(0.015)**
tall shrublands, open forest	birds that forage or roost in more open foliage	.019 - .023 **(0.02)**
tall shrublands, open forest	birds that forage in denser foliage	.027 - .037 **(0.03)**
open forest	foliage-foraging birds	.040 - .070 **(0.05)**
open forest with shrub understorey	foliage-foraging birds	.080 - .100 **(0.10)**
forest with shrubs and dense foliage	foliage-foraging birds	.140 - .170 **(0.15)**
dense, long grass in grassland	cryptic, small ground vertebrates	.140 - .260 **(0.20)**

Population density 'guesstimate'. Population density affects the height of the detection distance frequency distribution curve, not its shape. Enter your *initial estimate* of density, stated as number of individuals per hectare (ha).

Base your estimate on previous knowledge if possible; it is important that the estimate is realistic. Because a hectare is a relatively small area (equivalent to 100m x 100m, or 2.47 acres), vertebrate population density will often be less than 1. [If you find it easier to estimate number per square kilometre, do that first then divide your estimate by 100 to convert it to no./ha. *E.g.* 5 per sq. km. becomes 5/100 = 0.05.]

Choose a *step size* identical to or slightly smaller than the initial estimate [*e.g.* 0.04].

Maximum recognition distance. This is a best estimate of the maximum distance at which you can recognise the animal with the unaided eye, in metres, without using binoculars. If your sample has at least 40 detections, allow the program to select its own estimate of maximum distance based on the distribution of detection distances in the data. To let the program do this, set the initial value at 0.

If you set an upper limit to the range of distances, or the data set is very small (<10), always supply your own estimated distance [*e.g.* 125]. Use the values given in Table 3 as a guide.

◆ ***Very small samples.*** If you have fewer than 5 separate observations in your sample, estimating population density by any distance sampling method is not recommended. With *WildlifeDensity,* trying to run the program with fewer than 12 detections is unlikely to work.

Important*:* *Always* save the data input file (a file with the suffix *.WDdata)* after entering any data and before running the program. (If you fail to do this, you may inadvertently use an earlier version and not notice.)

- ***Saving input files.*** Choosing Save or Save as in the File menu lets you save the data input file in *WildlifeDensity* format (with suffix .WDdata) within a folder on the computer. Saving it also 'flags' the file with a *WildlifeDensity* icon. Selecting its icon or name in a list of folder contents then directly opens the program.

  (*.WDdata* files can also be opened and examined as a text file using a text program such as *BBEdit* or *TextEdit*. To do this, either drag-and-drop the files on to the program icon or open the text program first and use its ***Open*** command to locate and open the relevant

Select the ***Estimate*** tab to open the final window used to run the program. It is described in the next chapter (Ch.9) on the next page.

Estimating Densities and Population Sizes

9

Opening an input data file. The easiest way to begin data processing is to have the *WildlifeDensity* icon in the dock. Double-click the icon of a prepared *.WDdata* file or drag an already-prepared data file to place the icon in the dock. The program usually opens at the Method tab (though it can also be opened in the other ways).

Once the program opens, make any last-minute changes you wish before running the program. This gives you a chance to alter your entries. You can vary the number of iterations, call for verbosity and debugging options if necessary, or even run the program without bootstrapping *(see p.70)*. Re-save an altered file.

Running the Program

Select the *Estimate* tab.

The program is run from this window. It should now show the number of observations (detections, not total individuals) in the input data and two control buttons: ' **Calculate**' and '**View results**'. The window also allows space for a progress bar and a results summary.

Before beginning. Unless you wish to preset the maximum recognition distance, check first under the Options tab that the number in the maximum recognition distance panel has been set at 0. To alter it, select the 'Select initial values . .' button, alter the entry to 0, save the file, then deselect 'Select initial values . .'. Go back to the Estimate tab.

Program operation. Save the input file if you haven't done so already. Now select the Calculate button to start the search for a 'best-fit' model to the data. Wait for the progress bar to complete. How long this takes depends on the numbers of iterations selected and observations entered, the variability of the group sizes and the speed of your computer. The sudden appearance of a graph and a results summary in the Estimate window marks the end of computation. The graph appears as a separate window that can be dragged around on-screen.

Now examine the output.

Computer output. The Estimate window should now display the **density estimate,** its **standard error** and computer paths to two output files: a main results file (*<filename>.results)* and an observed and calculated numbers in each class file (*<filename>.graphData).* If a computer run is repeated, this pair of files is produced each time and given the same name but with a different version number immediately after its filename (*e.g. <filename> 1 .results, <filename> 2.results).*

Comparison graph. A comparative plot, drawn from the numbers in the *<filename>.graphData* file, should appear in a separate window (often above the output window). It uses the class interval you chose initially to show the detection distance frequency distribution as coloured dots joined by dashes. It also shows the numbers calculated by the *WildlifeDensity* model as a yellow continuous line.. (You can reopen this graph at any time by dragging and dropping the *.graphData* file on to the *WildlifeDensity* icon in the computer's dock. You can enlarge the graph either by dragging its bottom right-hand corner to the right and downwards or selecting the third button from left at the top left of its window. To reverse the latter process, press the computer's ESC key.)

Comparing the two distributions can show whether or not the computer run reached an appropriate solution. It will also help you identify any mismatching of the two distributions and show if you need to rerun the program. The graph is to help you identify any mismatching of the two distributions and show whether you need to rerun the program. If the model and the data shown in the graph correspond, you can accept its estimates of population density and the other parameters.

Once the program finishes, selecting the ***View results*** button on the Estimate window opens the current *<filename>.results* file and displays the program inputs and outputs in text format. It will open in whichever text application you have selected.

Reviewing the Program Output

Select the View results button and examine the information listed under '**Input**' to check that the survey details were entered correctly before you consider how well the model fits the data.

Examine the distribution. Compare the calculated distribution with that of the observed field data. If the yellow line follows the data along most of its length (*Figure 26, next page*), consider the search satisfactory. The estimates and standard errors of density in the program's results should be reliable. Some observed values will be higher and some lower than the calculated values but — overall — one set should not be clearly above or below the other across any sizeable range of distances. Nor should the calculated parameters be a set of zeroes. In either case the search for a minimum difference has failed (see *Figure 27)*.

If that is the case, disregard the results so far, go to ***Chapter 10 : Troubleshooting*** on p.89, and prepare to resubmit your input data file after some appropriate changes. Otherwise continue with reviewing the output as described below.

Figure 26 exemplifies the expected goodness-of-fit between an observed radial distance frequency distribution and that modelled by *WildlifeDensty*. The two distributions follow very much the same overall path. A similar result is achieved with perpendicular distance and fixed observing point data, although the overall shape of the distributions alters with the type of distance data used, as already described in Chapter 1.

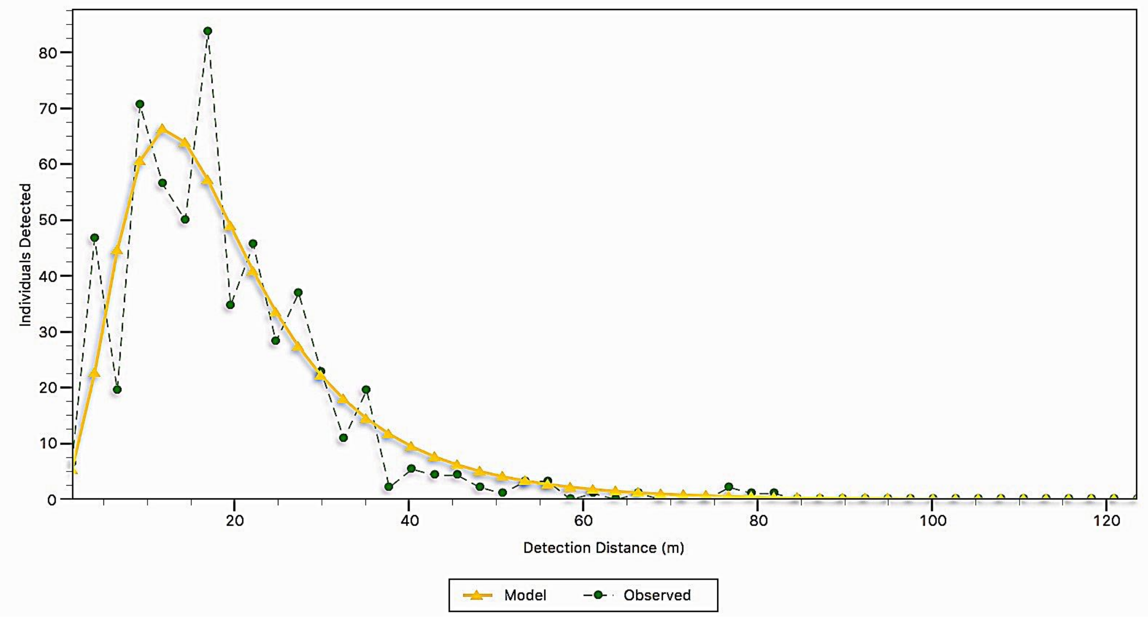


Figure 26. The fit of a modelled radial detection distance distribution (*yellow line*) to the numbers of a honeyeater population *(black dots)* observed at different radial distances from an observer walking a set of line transects. The line follows a path that corresponds approximately to the path followed by the data points. *(Based on a combined sample of 544 observations made under relatively uniform survey conditions.)*

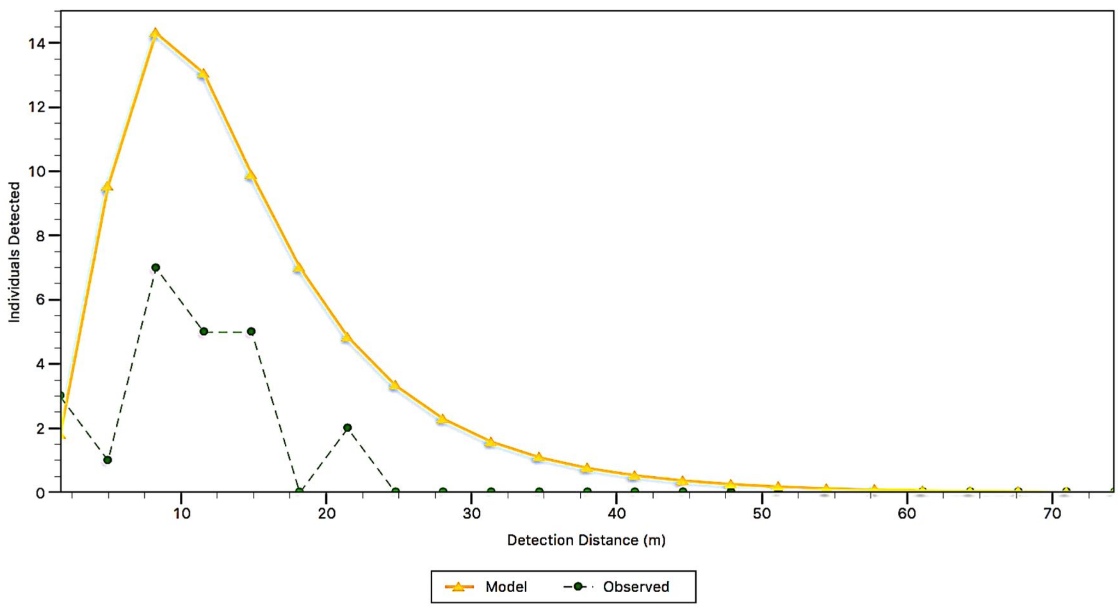


Figure 27. A poor fit fit of a modelled small sample distribution of a honeyeater population (*yellow line*) to the observed numbers *(black dots)* of detections at different radial distances from an observer walking a set of line transects under relatively uniform survey conditions. This time the modelled numbers and data points do not match. *(Based on a sample size of 23 separate detections.)* The difference between the two distributions shows that function minimisation is incomplete; the calculated density estimate will be unreliable. If this occurs, especially with a small sample, refer to Chapter 10 on p.89.

Results summary. Once the program has run successfully, selecting the ***View results*** button opens the current *<filename>.results* file to display the program inputs and outputs in text format. The .results file can also be opened at any time by double-clicking its file name.

Interpreting the Results

The output from program *WildlifeDensity* is in two files: the main results file, called *<filename>.results*, and a file that compares the original and modelled frequency distributions, called *<filename>.graphData.* Both output files should be in the same folder as the data input file, and both are printable.

The .results file. The main results file sets out some of the main inputs to the program, together with the population density estimate, its standard error, and a variety of other outputs, as follows:

INPUT:

Data type: the type of data processing selected.

Transect sides: whether observations were made on one or both sides of the transect line.

Class interval width: usually the class interval width submitted, unless this would subdivide the data into more than 80 classes, when it is set automatically at 1/80 of the maximum recognition distance.

Total transect length: in metres.

Total time spent: in minutes.

Overall population movement rate: the overall population movement rate entered, in metres/min.

Topography: the overall topographical attributes entered.

OUTPUT:

Number of Groups in Distance Range: the total number of animal groups (separate observations) within the selected data range.

Number of Individuals Detected Ahead: the total number of individual animals detected ahead of observers in the selected data range.

Number Overtaking: the total number of individuals overtaking observers from behind.

Height Difference from Eyelevel: either the root mean square height difference between the population of interest and observer eyelevel calculated from elevation angles submitted, or an approximation supplied by the user. Considerable height differences tend to reduce detectability.

Movement Correction Factor (J): a correction factor, calculated from population and observer rates of travel, to allow for the effects of relative movement on the numbers detected during line transects.

Adjusted Transect Length (LJ): the product of overall transect length and the movement correction factor.

Topographical Cover Value: an index to indicate the amount of topographical heterogeneity in the census area (higher values indicating a hillier terrain).

Maximum Detection Distance: the maximum detection distance, in metres, either estimated from the detection distances in the data set or supplied by the user.

Number of Parameter Estimations: the number of (bootstrapped) iteration sets carried successfully to completion by the program. If that number is less than the number you set in the Options window, this indicates that some analyses of bootstrapped data sets did not carry successfully to completion. (Failure to complete some analyses may indicate highly variable data, or very small samples, or inappropriate initial and step values for the parameters.)

Estimated Density (D): the estimated population density and its standard error, expressed either in numbers per hectare or numbers per square kilometre, as indicated. (Standard errors of the parameters are the standard deviations of the estimated 'best values' produced by the multiple iterations of the program, not the standard errors of their means.)

Conspicuousness Coefficient (a): the estimated conspicuousness coefficient for the population of interest under the conditions of the census (habitat, weather, observers) and its standard error, expressed in metres.

Lateral Cover Proportion (c) or ***Attenuation Coefficient (b)*****:** the estimated proportion of cover (vegetation, atmospheric dust or haze) in a line of sight between the observer and animals or, in some circumstances, the estimated attenuation coefficient for light or sound passing from an animal to the observer.

95% confidence limits for density estimates: Estimates of the lower and upper confidence limits of the density estimate, calculated by assuming a lognormal distribution of the estimates.

Detectability Coefficient (S): an overall general detectability coefficient for the population under the prevailing census conditions, together with its standard error, capable of being used not only to express overall detectability but also to enable density estimation without using distance data (see the full Guide).

Est. Detectability at g(y=0): an estimate of the probability of detecting all individuals along the transect line itself under the prevailing census conditions (=1.00 if all are detected; less than 1 if some individuals are undetected).

Final Difference at Minimum: the minimum function value, i.e. the sum of the squared differences between observed and expected frequencies at its search minimum end-point. Its value varies not only with the goodness of fit but also with the numbers of observations and the number of classes into which the distributions were divided. Very high values (e.g. >10,000) may indicate that the program has selected an inappropriate minimum point.

The output from fixed point data runs is similar; that from quadratic surface fitting (p.A18) differs in a few respects but is essentially similar.

The .graphData file. The second output file, *<filename>.graphData*, sets out and compares the 'best-fit' model, as calculated, with the original data submitted in the data input file. These are the data plotted in the output graph.

Both output files should be in the same folder as the associated data input file.

Printing and Exporting Results

Text file output. The two text output files (*.results* and *.graphData*) are added automatically to the folder with the *.WDdata* file when the computer run ends. The *.results* file contains the main results of the run, while the *.graphData* file compares the calculated frequencies with the observed data for each class distance interval.

Both types of file can be read by any text-based program and printed as such: just open the file and follow the usual Print commands.

Graphical output. The graph produced by *WildlifeDensity 2* is visible in a window called *<filename>.graphData* until you close it, when the graph is lost. To redraw it:

1. Locate the *.graphData* file in the folder with the *.WDdata* file. Instead of simply opening it, hold down the Control key while you click on the *.graphData* file. A popup panel should open.
2. In that panel, go to 'Open With' and click on the name of the most recent *WildlifeDensity* program. The graph should open once again.
3. Alternatively, close the *.WDdata* file, then reopen it. The last graph you drew should appear once again, behind the program window.

If you need to save a copy of the graph, use program Grab (built into the Utilities folder in Macintosh computers) before you close it. Proceed as follows:

1. Open *Applications/Utilities/Grab*.
2. Using the mouse cursor, drag the bottom right-hand corner of the graph window downwards and to the right until the graph has a shape you prefer.
3. Select the Grab icon now visible in the dock.
4. In the menu bar, select *Capture/Window*. A window called 'Window Grab' should open.
5. In that window select *Choose Window*, then click on the graph itself. A copy of the graph (in .tiff format) will open on the computer screen.
6. Save this graph, giving it a suitable name and location. This graphical image can be stored, printed and converted to a PNG, JPG, EPS or PDF format if desired.

Calculating Overall Population Estimates

If you have subdivided the survey data into sets of different detectability, you can make an overall population density estimate for the whole survey using stratification methods (*i.e.* treating each estimate as a layer, or *stratum*, of the survey—like a sedimentary rock built up of individual strata). To

do this, treat the different data sets as individual strata, weight the density estimates from each and add together the weighted estimates. The procedure is as follows :

1. Work out weights. Useful bases for weighting are *(a)* the proportion of the total area occupied by each habitat type (if all the data subsets are based on vegetation), or *(b)* the proportion of the total survey time or total survey transect length occupied by each subset. Each approach assumes that your placement of transects or sampling points has independently sampled the population's distribution in the field.

Work out what proportions of the total area, total survey time or total transect length were represented by each of the data subsets (whether based on habitat type, and/or other factors). Express each weight as a proportion (with a value between 0 and 1). Check that the full set of weighting proportions adds to 1.

2. Make an overall density estimate. Calculate an overall density estimate (*D)* for the entire survey area as:

$$D = \sum_{h=1}^{l} W_h d_h$$

where D = the overall density estimate,
$\sum$ = the sum of a series of terms,
h = the hth stratum,
l = the number of strata,
W_h = the weight of the hth stratum, and
d_h = the density estimate for the hth stratum,
as outputted by the computer.

[For example, if there are two habitat types (the strata), with the first habitat (say, forest) occupying 60% of the survey area (W=0.6) and the second (say, woodland) occupying 40% (W=0.4), and the density estimates for each were 1.23 and 0.56 respectively, then the estimated overall density D is:

D = (0.6 x 1.23) + (0.4 x 0.56) = 0.738 + 0.224 = 0.96/ha]

3. Estimate a standard error. An overall standard error can be estimated by calculating:

$$S_D = \sqrt{\sum_{h=1}^{l} (W_h)^2 \,.\, s_h^2}$$

where S_D = the standard error of the stratified estimate, and
s_h = the standard error of the hth stratum,

as outputted by the computer runs..

[Thus, for the example above, if the standard error of the density estimate for the first stratum (forest) was 0.102, and the standard error for the second (woodland) was 0.076, the standard error of the overall density estimate is:

sD = √{(0.62 x 0.102) + (0.42 x 0.0762)}
= √{(0.36 x 0.01) + (0.16 x 0.0056)}
= √{0.0036 + 0..0009}

$= \sqrt{0.0045} = 0.07/ha$

The estimated population density of the targeted population can then be expressed as:

$$D = 0.96 \pm 0.07 \text{ individuals per hectare}$$

The ' ± ' term here indicates plus or minus one standard error.]

4. Confidence intervals. If you need to know the 95% confidence limits of a density estimate, these can be calculated in the usual way for a normal distribution (which the distribution of D approximates). The lower (L_1) and upper (L_2) confidence limits are given by:

$$L_1 = D - t_{\alpha(2)}.s_D$$
$$L_2 = D + t_{\alpha(2)}.s_D$$

where t = Student's t *(see statistical tables),*
$\alpha(2)$ = the probability level (usually 0.05) for a 2-tailed distribution.

For a large sample (*i.e.* a large number of bootstrapped iterations in this case), t is approximately 2 for α=0.05, making $L_1 \approx D - 2s_D$ and $L_2 \approx D + 2s_D$.

[For the example here,

$$L_1 = 0.96 - (2 \times 0.07) = 0.96 - 0.14 = 0.82/ha$$
$$L_2 = 0.96 + (2 \times 0.07) = 0.96 + 0.14 = 1.10/ha$$]

5. Estimate the Total Population. A total population estimate is made by multiplying $D \pm s_D$ by the total survey area.

[So, if the total area containing the target population was 2167 hectares then, rounding to the nearest 10, the total population estimate is

$$\text{Est. Total Population} = (D \pm s_D) \times \text{Area}$$
$$= (0.96 \pm 0.07) \times 2167$$
$$= 2080 \pm 150$$]

Troubleshooting

10

Provided you have sufficient field data, and those data were collected and entered correctly and completely, the *Wildlifedensity* program should proceed to completion automatically. This is the normal or default situation Occasionally, though, the program does not work as expected. This chapter deals with such problems. A common one is that the calculated frequency distribution shows a poor fit to the field data, especially with smaller samples when the numbers detected were low..

Processing Small Samples

Field surveys of birds, mammals and other land vertebrates often produce few observations, even with extensive fieldwork. Is it possible to get useful density estimates from *WildlifeDensity* when this happens? The answer is often 'yes', especially with *WildlifeDensity_*2.2 onwards. It depends on the number of observations in your sample and on how variable the cluster sizes were. Large, even samples, properly collected and entered, should give few problems. Unless you selected the third verbosity and debugging option below the Options tab, the program will normally proceed to completion automatically. However, processing difficulties are encountered occasionally with smaller samples. *WildlifeDensity* initiates some automatic processing when detection numbers are less than 260.

With smaller samples, unless you select the third verbosity and debugging option under the Options tab (*see below*), the program will usually proceed to completion automatically, though with a difference. It will use the distribution of detection distances in the sample to estimate the amount of lateral cover between observers and the population. The program then fixes or pre-sets cover at that value before going on to estimate population conspicuousness and density. Doing this has little effect on the density estimate, but makes estimates of the shape parameters approximate only (*see below*).

Once the run has finished, examine the graph to assess how well the yellow line fits the data points. If the line follows along the path of the data points approximately, consider the computer run satisfactory. The density estimate and its standard error should be dependable, but estimates of other parameters will be approximations.

If the fit is still poor . . . . In a minority of cases, particularly at the lower end of sample sizes (*esp.* under about 40 detections with radial data and under 80 with perpendicular data)), the fit of the modelled line to the data may still be disappointing (as in Figure 27). The search for a 'best fit' solution ended during processing, before the modelled distribution fitted the data. If that happens, you can try pre-setting conspicuousness instead of lateral cover (*Strategy 1*).

Strategy 1 — preset conspicuousness instead of cover

1. Open the *WildlifeDensity* app.

2. Select the Options tab.
3. Select the '**Select initial values and options manually**' button.
4. For **Conspicuousness coefficient,** enter an initial estimate (e.g. 9) and enter a zero (0) for step size.
5. For **Lateral cover,** enter a suitable value for both the initial estimate and the step size (e.g. 0.05, and 0.05).
6. For **Population density**, enter a suitable value for both the initial estimate and the step size (e.g. 3 and 3).
7. For **Maximum recognition distance**, enter a zero (0)
8. Under **Verbosity and debugging options**, select the bottom line, viz. 'Tabulate final estimated function values for each distance class'.
9. Save what you have entered (i.e. 'Save' under the File menu).
10. Under the Estimate tab, select the **Calculate** button.
11. When the computer run finishes, deselect the 'Tabulate final estimated values . . ' button at the bottom of the Options tab window.

All being well, the program should now have achieved a good fit of the model to the data. If it still hasn't, try pre-setting both shape parameters (*Strategy 2*).

Strategy 2 — preset both cover and conspicuousness

1. Select the Options tab.
2. Select the '**Select initial values and options manually**' button.
3. For **Conspicuousness coefficient,** retain the initial estimate (e.g. 9) and enter a zero (0) for step size.
4. For **Lateral cover,** retain the initial estimate (e.g. 0.05) and enter a zero (0) for step size.
5. For **Population density,** retain a suitable value for both the initial estimate and the step size (e.g. 3 and 3).
6. For **Maximum recognition distance**, either enter a zero (0), when it will estimate that distance from the data entered, or enter a maximum recognition distance calculated by entering and running a pooled data set for that species from the survey site, then reading the distance from the .results file. (The second option should give you a better estimate of the maximum distance.)
7. Under V**erbosity and debugging options**, select the bottom line, viz. 'Tabulate final estimated function values for each distance class'.
8. Save what you have entered (i.e. 'Save' under the File menu).
9. Under the Estimate tab, select the **Calculate** button.
10. When the computer run finishes, deselect the 'Tabulate final estimated values . . ' button at the bottom of the Options tab.

The program should now have reached a final solution. Note though that pre-selecting both shape parameters tends to under-estimate the standard error. Using a larger dataset is — as ever — the preferred option.

Don't consider your task complete until you have a model that clearly fits your data; when it does, the density estimate it produces should be as reliable as your data set allows. If you decide your sample(s) are too small and you really need more data, be prepared to go out and collect it!

On pre-setting shape parameters. Pre-setting a shape parameter is particularly useful for achieving a density estimate when you have a smaller-scale sample (<250). When the results of pre-setting conspicuousness are compared with results where both shape parameters vary freely, the outcomes are instructive. Pre-setting conspicuousness has only a comparatively small effect on the density estimate and its standard error (which may reduce slightly). The estimate of lateral cover is little affected either, but its standard error is reduced significantly. Pre-setting one shape parameter is a useful strategy if a reliable density estimate is your primary objective.

Pre-setting either conspicuousness or lateral cove makes the estimates of both shape parameters by the program unreliable. During the curve-fitting process, error in one shape parameter is roughly compensated for by error in the other shape parameter with relatively little effect on the shape of the frequency distribution. Because population density affects the overall height of the distribution rather than its shape, its estimated value can remain relatively dependable even when a shape parameter is pre-set. Examine Figure 28.

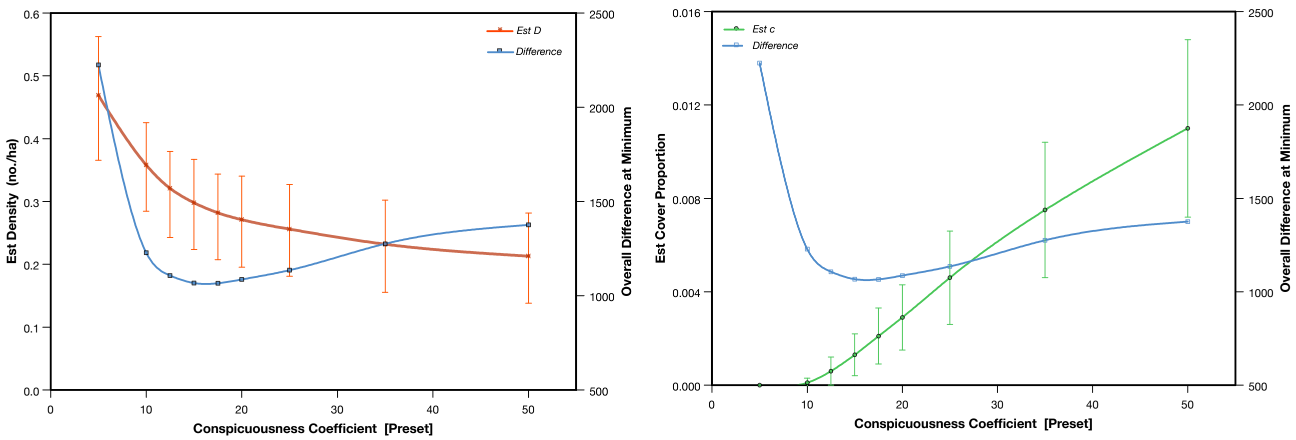


Figure 28. The effect of pre-setting one of the shape parameters (conspicuousness) on estimates of density (*in red, left*) and the other shape parameter, cover, (*in green, right*) in a sample of 63 observations. Both density (*left*) and cover (*right*) have been plotted against conspicuousness. The goodness-of-fit between observed and calculated values is shown in both graphs too by using the same blue line.

The overall difference has its minimum — its best fit value — at a conspicuousness of 17 and a cover value of 0.002, where density is 0.29 ± 0.07 ind./ha. A much larger sample (282), run without any pre-setting, gave a similar density estimate and best estimates of 16.6 for the conspicuousness coefficient and 0.0019 for cover.

Notice in the right-hand graph how one shape parameter, lateral cover (*green linel),* increases with increases in the other shape parameter, conspicuousness (*bottom scale*), during the search for a minimum difference between observed and calculated frequency distributions.

Problems with Manual Selection, etc.

Searches for minimum values can fail for a number of reasons, particularly with manual selection of parameter values and step sizes. Sometimes initial values and steps supplied are poorly chosen. A useful analogy for the search process is to picture the user as a helicopter pilot flying over a rugged landscape looking for a village which they have been told lies in the deepest valley in the district. The initial values tell the pilot where in the numerical landscape to start looking, and the step sizes how far to look to either side. If the initial values are far from correct, the program begins its search in the wrong part of the landscape. It finds the 'deepest valley' in that local area and puts down at the wrong 'village'. The resulting parameter values then model the data quite poorly. *It is therefore important — if you are that you choose initial estimates and step sizes wisely* to give a reasonable chance of finding the correct endpoint.

Unsuitable parameter starting values. The search for a successful match between the distance distribution of the original data and the calculated model depends on the starting values provided and the initial step sizes used. *If you have used your own starting values*, the initial parameter values (conspicuousness coefficient, cover proportion and population density) may be nowhere near their 'best-fit' values. The search can then become 'lost' — fail to converge on the best solution. If you think this has happened, re-examine the values you first submitted. Change them, and the relevant step sizes, to what you think may be better, and rerun the program.

Insufficient data. Any curve-fitting program needs enough data to show the frequency distribution clearly and allow the program to model it. If you think you may not have enough data, first examine the frequency distribution of the field data and decide whether or not you think its shape is clear enough to model. If you decide you have enough data, look at some of the other possibilities below. But if you decide you really do need more data, some additional fieldwork may be in order!

Cluster sizes extremely uneven. Sometimes there are a few very large clusters (herds, flocks) of individuals in a data set with many much smaller groups. Once the random resampling process begins, such clusters may be selected by chance quite different numbers of times. This can sometimes have a big impact on the shapes of the distribution curves.

There are ultimately two different solutions to this problem. One is to accumulate very large data sets whenever this is happening. The other is to ensure that all group sizes are as small as possible. Group sizes for use with *WildlifeDensity* should be based on the distance between individuals where a group member was first detected, not on whether or not the animals tend to move together. If you think the groups you are using might be too large to reliably indicate detection distances, try making sure that all members of a 'group' are close to one another and roughly the same distance from the observer *whenever data are being collected in the field.*

Population well above or below observer eyelevel. Another type of data set can produce problems in modelling: one where the population is located either high above or far below observer eye-level, especially when the measurements are perpendicular distances. The shape of the frequency distribution is then not particularly distinctive—a common difficulty with perpendicular distance data. That makes many different solutions to the modelling process possible. In such cases it pays to have a very large data set.

Carelessly-collected data. A data set may also include too much error to use with this technique, especially if field staff lack either motivation or training. A common cause is using poor

measurement techniques, such as relying on guesswork rather than measuring distances, and continually ‘rounding-off’ distances to the nearest 10 or 100 m. Another is inattention, resulting in animals either being missed altogether or distances being measured long after animals first became visible, resulting in radial distances that are too short. Still another is inability to identify the species correctly . . . and so on. There is no alternative to using *great care in collecting field data*; and having competent, highly-motivated field workers is paramount. (Otherwise an old maxim applies once data are submitted to the program: “Rubbish in, rubbish out”.)

Don’t consider your task complete until you have a model that clearly fits your data. When it does, the density estimate should be as reliable as your sampling design and sample size allows. If you need accurate values of a shape parameter, or have any reason to doubt the accuracy of a density estimate, or need higher precision, remember that best estimates are made by modelling *when you have a large, carefully collected data set*. If your data set is small, consider collecting more field data so you have more data to model, particularly if you have fewer than 15 detections If you really need more data, be prepared to go out and get it!

Program Won’t Run

If no program window appears, the data in the file have not been entered correctly and can’t be parsed by the program. If this happens with data entered in the *WildlifeDensity* GUI, double-check the various tabbed windows to see that all necessary data have been entered correctly. Locate and correct whatever is amiss with the data file. Sometimes the program behaves unexpectedly. Possible causes include:

Entries omitted. The program requires that every one of the data rows has its full set of values present; if just one is missing, the data set as a whole won’t parse.

Unsuitable characters present. Make sure there are no unsuitable characters (*i.e.* those with particular meanings in standard computer language, such as quotation marks, slashes and question marks) anywhere. If so, replace them.

Wrong type of number. Some of the data you are submitting are measurement data: these can take any value and may include a decimal point. Other data submitted (*e.g.* counts) are integers: whole numbers without any decimal points. Make sure you haven’t unintentionally used a decimal value where an integer number is expected.

Errors in data entered. If the program is performing in unexpected ways, check the data entered under the Observations tab to make sure there are no errors. Are all the relevant data in the correct columns? Do the entires across each row match those in the original data? Are there any blanks in a row where a number is expected?

Blanks between whole rows are ignored by the program. If you include blank rows, for example above and below the block of observational data, it sometimes helps clarity Once you locate a formatting problem and correct it, save the revised input data file and resubmit it to *WildlifeDensity*.

Verbosity and Debugging Options

At the bottom of the *Options* tab window on the GUI are three additional options. Each, if selected, will provide technical detail for troubleshooting the model computation process. The output of each is included within the *.results* file. There can be considerable output. The options are as follows:

Difference minimisation and parameter values. This option lets you follow the process of function minimisation, first with the original data and then with each set of bootstrapped data. The six columns show, in sequence the —

internal evaluation number,
minimum overall difference between observed and calculated values,
estimated *conspicuousness coefficient*,
estimated *lateral cover* proportion,
estimated *density x survey attributes* (e.g. transect length), and
the supplied or calculated *maximum detection distance*.

All are expressed in scientific or E (exponential) format, e.g. 0.122604E+02, which translates to '0.122604 times ten to the power +02'. (To read this in standard number format, move the decimal point two places to the right, when it becomes 12.2604. If the E value is negative, move the decimal point the stated number of places to the left.) These values are output every 1-3 internal function evaluations of a data set. Difference values tend to become smaller until the end of the series of evaluations is reached, while the other parameters tend towards their estimated 'best' values. If you see the letters 'NaN' anywhere, that means 'not a number'. If the program has not converged on a minimum after 750 evaluations, the process terminates without returning any parameter estimates for that particular data set.

Progress frequency distributions and minimisation outcomes. The second option shows the frequency distributions of detection distance for the original data set (labelled 'Bootstrap Replicate No.1') and each bootstrapped data set ('Bootstrap Replicate No.2' onwards). The tabulated values are the total numbers of individuals in each class, beginning with the class nearest the observer or transect line. It also reports the number of internal function evaluations needed to converge on a minimum difference and, in sequence: the conspicuousness coefficient, cover proportion estimate, density x survey attributes estimate, and the maximum detection distance. The minimum function value for that distribution is also provided. If no convergence results appear for a particular distribution, the search for a minimum had not finished within the preset maximum 750 evaluations.

Final estimated function values for each distance class. If the third option is selected, the results file shows in sequence the final calculated values of the following for each distance class, beginning with the most distant class and centred on the relevant radial or perpendicular distance value:

the *probability of detection P(r)* at a radial distance r, given its presence,
the *proportion Q(r)* of the population still *undetected* at r,
the *probability density function (p.d.f.)* for presence and detection combined,
the *expected total number E{N(r)}* detected in that radial distance class, and
the *expected total number E{N(y)}* detected in that perpendicular distance class.

If the inner boundary of the final (nearest) class has reached the P=.001 level, it also prints out a 99.9% r value: the minimum radial distance from the observer (r_{min}). This is the distance, in m, by which 999 of 1000 individuals would have been detected according to the probability density function. If this reports a zero, individuals are probably being missed along the transect line itself.

PART FOUR :

FURTHER OPTIONS

Other Survey Situations 11

Sometimes a survey situation differs from those described earlier. This chapter deals with three of them. The most common involves a data set too small to have its detection distance distribution modelled as reliably as we would like. Another involves target populations that are not dispersed throughout the survey area, with observations possible in any direction and to any distance, but are restricted instead to a belt of fringing vegetation between a roadway and open farmland. A third situation involves physically large animals dispersed over too large a land area to be surveyed easily by observers on the ground, but are surveyed from aircraft instead. The chapter ends by consideing the applicability of line transect and fixed point techniques to wildlife surveys generally.

The Problem of Small Sample Sizes

A familiar problem with animal abundance surveys is that, despite extensive sampling and considerable time, you manage to detect only a few members of the target population. With distance sampling, for example, you simply make too few observations to model the distance distribution well and go on to make a dependable density estimate.

Two options. There are at least two possible solutions. Both depend on your collecting data at your survey site more than once. This works with *WildlifeDensity* because it models key survey parameters.

1. Repeat your population survey at the selected site on as many occasions as you can, making sure that observing conditions are similar each time (*e.g.* similar survey type, transect placement, weather conditions) and that observers are careful when making observations in the field to meet all the assumptions of this technique (see Chapter 1, pp.22-24). If conditions alter for a time (*e.g.* a heavy rainstorm), suspend the survey until 'normal' conditions resume. Record each data set separately.

   When you think you have enough observations in total, combine all your detection data, all your site data (*e.g.*transect length, time spent, topography) and movement rate data into a single (pooled) dataset. Then run it to *WildlifeDensity* as described in Chapters 9 and 10 (pp. 81-90). This procedure can work well.

2. Prepare a pooled data set as just described, run the pooled data on *WildlifeDensity* and record the value of the detectability coefficient *(S)* returned in the *.results* file, together with its standard error. Use this to ***estimate density by the detectability approach for repeated surveys*** described in the next part of this chapter. This approach also has the advantage that repeated surveys can be carried out without having to measure detection distances every time. This is helpful if rangefinders are unavailable or survey personnel at your disposal are relatively unskilled.

The Detectability Approach for Repeated Surveys

As set out in earlier chapters, a population's detectability under a given set of observing conditions depends on such factors as the conspicuousness of individuals to the observers, the amount of vegetation cover, the topography, ambient weather conditions, and any height-above-ground difference between the observer and the population. Given a set of data collected under a particular set of conditions, the overall effect of such factors on detectability can be summarised by a single mathematical function, called ***the general detectability coefficient***.

The general detectability coefficient for a given set of conditions is a number, represented by '*S*' in Equations 11 and 12 below. An estimate of its value and that of its standard error 'SE_{S}' are returned in the output for each run of *WildlifeDensity* (neat the bottom of the *View results* window).

Once you have a value for S, observers can repeat the original set of transects, identify and count individuals and groups, and record certain other survey data (such as the times of starting and ending a transect), but no longer need to measure detection distances or sighting angles. Then estimate density from either Equation 11 or Equation 12 below.

To estimate density and its standard error from line transect data, use Equations 11 and 11a:

$$D = \frac{c.N}{n_S LJP_d S} \qquad \text{— Eqn. 11}$$

where
D = the density estimate;
c = a scaling factor (10,000 to express densities in no./ha, 1,000,000 to express them in no./sq.km);
N = the total number of individual animals detected;
n_s = the number of sides of the transect line scanned;
L = the total transect length, in metres;
J = the movement correction factor *(see next page)*;
P_d = the proportion of the population detectable; and
S = the general detectability coefficient for the data set.

$$SE_D = \frac{cN}{n_s LJP_d S_{SE}} \qquad \text{— Eqn. 11a}$$

where
S_{SE} = standard error of the the detectability coefficient.

Or, for fixed point data, Equations 12 and 12a:

$$D = \frac{c.N}{2ut\, p_s P_d S} \qquad \text{— Eqn. 12}$$

where
D = the density estimate;
c = a scaling factor (10,000 to express densities in no./ha, 1,000,000 to express them in no./sq.km);
N = the total number of individual animals detected;
u = the overall movement rate of the species in m/min;

t	=	the total time spent observing, in minutes;
p_s	=	the proportion of an observing arc scanned;
P_d	=	the proportion of the population detectable; and
S	=	the general detectability coefficient for the data set.

$$SE_D = \frac{c.N}{2ut\ p_s\ P_d\ S_{SE}} \qquad \textbf{— Eqn. 12a}$$

where S_{SE} = standard error of the the detectability coefficient.

The detectability coefficient defined. The detectability coefficient *S* is the ratio between the number of individuals detectable per unit of transect length (*e.g.* per metre) and the mean number of individuals present per unit area (*t*he overall density in no./sq.m). For line transects, number per unit length = the total number detected / [total transect length x 2 (if both transect sides used).] A low value of *S* means individuals are hard to detect (*e.g.* inconspicuous animals, amongst dense cover) whereas a high value means detection is relatively easy (*e.g.* conspicuous animals, in open habitats).

Every run of program *WildlifeDensity* returns an estimate of the detectability coefficient for the particular conditions (e.g. species, habitat type) of that survey. That value can be used in the above equations for other surveys where observing conditions are similar (*e.g.* repeat surveys in the same habitat). *WildlifeDensity* also returns estimates of the movement correction factor *J* needed for Equation 11. *J* can also be estimated graphically *(see below and Figure 29 on next page).*

Using *S* to estimate population densities. Estimating density in this way doesn't require data on detection distances or sighting angles—simply the total numbers detected and the relevant data on the sampling situation. Density estimates can then be made for a data set of any size, from a single transect or sampling point to multiple samples involving a large number of detections. They can also be made with subsets of a single survey on a transect-by-transect, section-by-section or sampling point-by-sampling point basis. Simply ensure you have all the data you need, then calculate a density estimate (*D)* for each using the appropriate equation, either by using a formula inserted within a spreadsheet or using a small calculator. The value of *S* can come from the *.results* files in previous runs of *WildlifeDensity*. The value of *J* (if needed) can come from the *.results* file if there has been a previous computer run of a data set from the transects concerned, or be estimated using the procedure below.

Estimating *J*. Usually the value of the movement correction factor *J* needed for line transect estimates can either be read from a conversion graph *(Figure 29)* or calculated for each data set using Equations 4a or 4b on pp.A6 in the Appendix. To do either, first work out the observer's overall movement rate *(w)* by dividing the transect length (in m) by the survey duration (in min). Preferably, use your own data on the species' overall rate of travel *(u)—see Chapter 5*—or make an approximation to it using Table 2 on p.75. The procedure is then as follows.

Calculate the ratio *k* = *u/w*. Estimate the movement correction factor *J* by reading the graph in Figure 29 or making an approximation: If the result is less than 5, calculate *J* from Equation 4a on p.A6; if *k* is greater than 5, use Equation 4b from that page. Then do the density calculation.

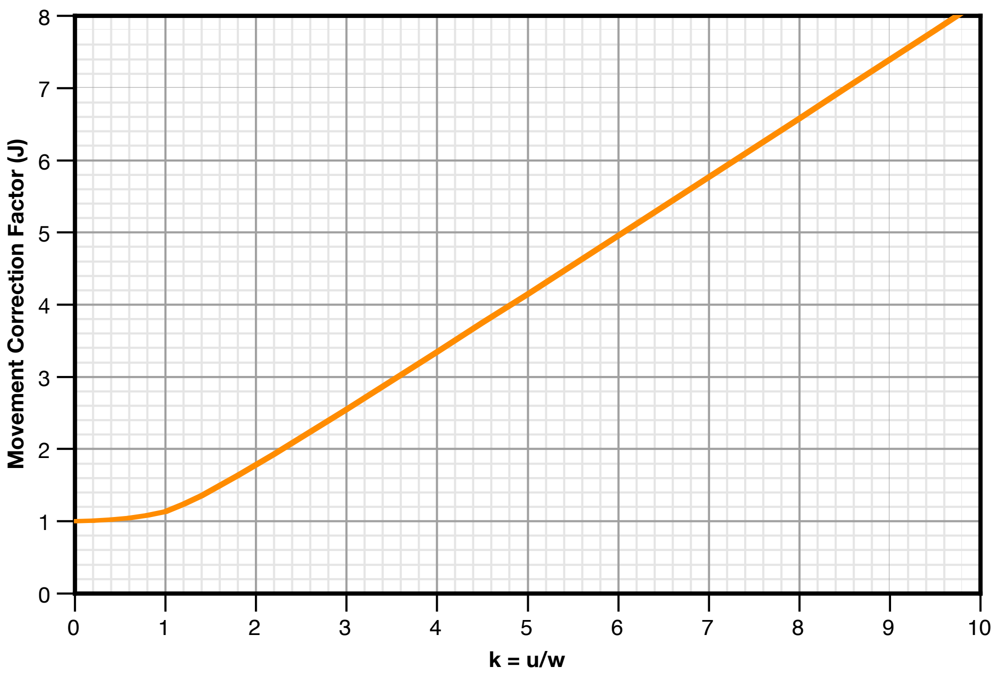


Figure 29. A conversion graph to enable estimation of the movement correction factor (J), given values of the ratio k between the overall animal movement rate (u) and the overall observer travelling speed (w). Grid lines here are spaced 0.2 units apart.

Standard errors of an overall density estimate. If you make a series of density estimates using Equations 11 or 12 for individual parts of a survey, you can calculate an overall mean and a standard error of the mean of a number series. Unfortunately that approach doesn't give you a usable standard error: they can vary widely, may have many zero values, or not follow a normal distribution, or be based on data with very unequal cluster sizes..

One option is to *regard density estimates based on the general detectability coefficient as convenient approximations* and not attempt to estimate an error term at all. Another option is to estimate the error in the way set out below.

Estimating an overall standard error. Much of the following procedure can be carried out on a spreadsheet.

1. *Make an initial computer run.* Put together an input file of data collected under similar conditions to those in your survey (perhaps from previous surveys at the same site or surveys elsewhere), run the data on *WildlifeDensity* and record the *S* value and its standard error from the *.results* output file. Check that the standard error is under 20% (one-fifth) of the *S* value. (*E.g*. a detectability coefficient of 50 should have an error of less than 10.) If it is lower, continue; if it is higher*, there is no point in going further*—your calculated standard error will neither be reliable nor useful.

2. *Create roughly equivalent data subsets.* Divide your survey data into subsets of data collected with roughly equal effort. For example, use data from individual sampling points in a fixed point survey collected over similar time periods, or data from transect sections of similar overall length (perhaps by pooling various combinations of smaller ones).

3. *Minimise the zero counts.* If there are many zero counts amongst your subsets, combine the data from individual subsets chosen at random, in (say) twos or threes, to make larger samples with

fewer zeroes amongst them. (Having fewer samples with zero counts than samples with 1 is a convenient working target.)

4. *Estimate subset densities.* Estimate a density for each data subset using Eqn.11 or 12 as appropriate. Examine the estimates to satisfy yourself that they follow a roughly normal distribution (especially, that they are symmetrically-distributed around the mean value, with the mean similar to the median.) If they are not roughly symmetrical, then transform your data using either a square root or logarithmic transformation, finally back-transforming at the end of calculations.

5. *Calculate a subsets mean and standard deviation.* Use the densities just derived to calculate a mean density *(D)* and a first standard deviation of the sample set *(s_d)* in the usual way.

a) *An initial standard error of the mean density.* Estimate the standard error of the sample mean density (SE_d) by calculating,

$$SE_d = \frac{s_d}{\sqrt{n}}$$

where s_1 = standard deviation of the sample set; and
n = number of samples in the set.

b} *A final standard error of the density estimate.* Estimate the standard error of the density estimate, taking into account the error in the detectability coefficient, using Equation 14 below. First calculate the following terms:

$$c_d = \frac{SE_d}{D}$$

$$c_S = \frac{s_S}{S}$$

where SE_d = initial standard error of the mean density;
D = mean density;
s_S = standard error of the detectability coefficient; and
S = estimated detectability coefficient.

Then complete the computation:

$$SE_D = D.\sqrt{[c_d{}^2 + c_S^2 + (c_d.c_S)^2 + 3c_S^4]} \qquad \textbf{– Eqn. 14}$$

Confidence limits for the density estimate. Provided that the estimates you used to calculate this standard error *(SE_D)* were symmetrically-distributed about the mean, the 95% confidence limits of the density estimate are given approximately by:

$$D \pm 2SE_D$$

or, more precisely, by $D \pm t_{.05}.SE_D$, where $t_{.05}$ *is* the 5% value of *Student's t*.

I.e. $CL_1 = D - t.SE_D$, and
$CL_2 = D + t.SE_D$

If you transformed your data at Step 4 above, now back-convert your confidence limits by squaring or taking antilogarithms of your mean and confidence limits (whichever is appropriate). Typical values of the general detectability coefficient for a number of Australian birds and mammals are given in Table 5 below.

Table 5. Sample values of the detectability coefficient *(S)* for a variety of Australian mammal and bird species, ranked from largest to smallest, and from the most open to the densest cover.

Taxon	Species	Habitat	Detectability Coefficient
mammals	eastern grey kangaroo	open grassland	200 - 300
"	"	woodland	120 - 140
"	western grey kangaroo	grassland	± 220
"	"	riparian woodland	± 125
"	"	dune woodland	± 85
"	"	mallee scrubland	± 70
"	black wallaby	woodland and forest	± 45
"	common brushtail possum	public gardens at night (by spotlight)	15 - 25
birds	emu	open grassland	450 - 510
"	ringneck parrot	eucalypt foliage	± 33
"	red wattlebird	eucalypt foliage	40 - 50
"	spiny-cheeked honeyeater	eucalypt foliage	20 - 40
"	swift parrot	open forest foliage	± 30
"	white-browed wood-swallow	perched and hawking above scrub	± 40
"	yellow-plumed honeyeater	eucalypt foliage	17 - 21
"	helmeted honeyeater	open forest foliage	16 - 21
"	"	forest foliage	13 - 17
"	"	dense foliage	5 - 12
"	weebill	eucalypt foliage	16 - 18
"	striated pardalote	eucalypt foliage	± 10
"	larks, larger quail	grassland	2 - 7
*	small quail	grassland	± 1

Using the detectability coefficient. Estimating densities using the detectability coefficient is an appealing option in some situations. No distance data or detection angles are needed; consequently

field observers have an easier task and require less training. (Although these data *are* needed initially to obtain values for *S* and its standard error.)   It has some other advantages too . . .

◆ *'Quick-and-dirty' density estimation.* You can use this approach to derive a quick 'ball-park' estimate of density with minimum effort by simply counting the individuals detected on transects or at fixed points and using a rough approximation to *S* in Equation 11 or 12. Much amateur field data then becomes usable. Table 5 opposite gives some typical *S* values for mammal and bird species that you may be able to draw on for species of comparable conspicuousness and way of life..

◆ *Exploring survey data.* The detectability coefficient method also makes it possible to break up an extensive data set from an area into small parts (*e.g.* individual fixed points) and obtain a density estimate for each part. This is achievable whatever the number of observations made — provided you already have values of the detectability coefficient to rely on.

◆ *Repeated surveys.* The detectability coefficient is also well-suited to long-term monitoring programs where skilled personnel may not always be available. A monitoring program can begin with a thorough line transect or fixed point survey in which all relevant data are collected and where computer runs yield values of the detectability coefficient. The same transects or fixed points can be then used subsequently under similar conditions, with field staff recording only the properties of the survey and the numbers of individuals observed. Density estimates are then still possible.

To make overall estimates of density from two or more of these density estimates, use the same stratification methods previously described in Chapter 9.

Linear Vegetation Belts

In some parts of the world, roadways and lanes through farmland retain belts of natural vegetation between the roadway itself and adjacent open fields, often on both sides of the road (*see Figure 30*).

Figure 30. Roadside koala habitat in south-eastern Australia. 25 koalas were detected in defined roadside belts along 14.58 km of roadway. Using *WildlifeDensity*, density in these belts was estimated at 0.63 ± 0.23 ind./ha. The true density by thorough searching: 0.69 ind./ha.

Linear vegetation belts like these provide habitats for some animal populations. However conditions are less than ideal for either line transect or fixed point surveys. You normally require fairly uniform observing conditions to a considerable distance in any direction ahead and to the sides. Instead, for an observer walking down the centre of the road, there is no vegetation directly ahead and at very short distances to either side (or only some high overhead) and none or very little beyond the road reserve boundary. Despite this situation, *WildlifeDensity* is still usable.

A case study. Koalas are sedentary arboreal mammals found at any height from ground-level to the crowns of the eucalypts on which they feed. In the survey area shown in Figure 30, the eucalypts lining the road grow to 45m in height. A central strip of foliage directly above the roadway had very few koalas, while the open fields beyond the edge of the road reserve had none; nearly all the animals were in the vegetation belts on either side of the road.

In a population survey that involved 14.6 km of walking, an observer recorded 27 koalas ahead, together with the horizontal distance, compass bearing and elevation angle to each detection point, and details of the transect conditions as well. In a detailed search of the same vegetation immediately afterwards by researchers who know the species well, 37 koalas were found. The actual density of the koala population in the roadside vegetation was thus measured at ***0.69 individuals per hectare***.

Data were then entered in *WildlifeDensity* with method details inserted as follows: perpendicular distance data, from a limited range of horizontal distances between 5 m and 21 m from the centre of the road (the transect line), and on both sides of the transect. The program was set to use a 2m class interval width. The survey period was 663 min, and the mean diurnal koala movement speed taken to be about 2 m/min. A run of the program estimated koala density in the vegetation belts on either side of the road at ***0.63 ± 0.23 ind./ha.***

A workable approach. This example illustrates the features of linear vegetation belts that determine the approach. The geometry of the roadside vegetation belts is different from the typical line transect situation, where there are similar observing conditions in all directions ahead. Where there are linear vegetation belts, observing conditions change both with direction and distance from the observer. A radial distance approach is not usable because the site's geometry affects detectability in a complex way. A fixed point method is not usable either unless the belts are very wide.

A perpendicular distance approach that uses only the data from within the actual vegetation belts is the appropriate one. A full set of line transect data is collected, and a perpendicular distance analysis carried out using only the observations made between the inner and outer edges of the belt, *i.e.* between the minimum and maximum distances from the transect line. The density estimates calculated by *WildlifeDensity* should then be a close approximation to the true density.

Aerial Surveys

In some parts of the world, where there has been a significant need and the resources available have allowed it, aircraft have been used in broad-scale surveys of relatively large birds and mammal;s, Well-known examples are certain herbivores of more open habitats (*e.g.* elephants in east Africa, kangaroos in inland Australia, deer in parts of North America). Such broad-scale surveys are often impossible on

the ground. In the past, much of this work has been done using high-wing monoplanes such as the Cessna 180 series. More recently, smaller helicopters have been used.

The aircraft are usually deployed to fly aerial transects, flying at an aeronautically-safe speed and an altitude of 200 or 250 feet (61 or 78 m), or even higher. Observers in the aircraft may either attempt to count all individuals in a strip (belt) of known width, or try to count the animals at all distances out to the side. Distance measurements are difficult due to the aircraft's rapid forward movement.

However it *is* possible to use *WildlifeDensity* and other distance sampling methods to estimate densities using data collected from aircraft provided that distance measurements can be collected in some way and the usual assumptions met. This is not too difficult with helicopters, but presents some problems with fixed-wing aircraft. Without attempting a full treatment of the topic, some comments about these and related techniques are made below.

Problems in counting from the air. Apart from cost considerations, using aircraft as an observing platform has some disadvantages.

- *Altitude.* Flying well above the target population can give observers in aircraft a more extensive view while at the same time not allowing a close approach to the animals; however detectability is usually reduced and animals more easily overlooked altogether than is the case for an observer on the ground. Furthermore, a fixed altitude is hard to maintain without unless an inboard radar altimeter is fitted to the aircraft.

- *Airspeed.* Both fixed-wing aircraft and helicopters travel relatively quickly. (For helicopter pilots this is regarded as 'good practice' because it allows the spinning rotor to act as a 'wing' in the event of engine failure.) However rapid forward movement can severely limit the time available to detect and count animals: animals can easily be missed altogether because the observer happens to be looking elsewhere at the instant an animal comes into view. And there is insufficient time to measure the actual detection distances and observing angles.

- *Search image.* An observer well above—even vertically above—an animal sees a very different image from that seen by someone on the ground: its shape can look unfamiliar. So detectability is different. Observers may then need special training to identify even familiar target species.

- *Noise.* Most aircraft are fairly noisy (certainly much noisier than an observer on foot), causing some animals to flush well ahead of the aircraft. Animals are then detected when moving away or are missed altogether; an observer may detect a fast-moving group fleeing to the either side of the flight path and miss those moving under the aircraft and out of sight.

- *Tree cover, weather and lighting.* If there is tree cover combined with strong sunlight or high winds, some species may move partly or wholly under cover and become difficult to detect from the air. Some species are then not sufficiently detectable to survey effectively.

Also, many aircraft are built in such a way that observers have to operate from a row of seats immediately behind the pilot, getting their view of the ground through a side window. This provides little or no view ahead and, in fixed-wing aircraft, allows less time to scan the ground nearer the flight path than further out. Specially-adapted mathematical models are needed to adequately describe the observing situation. Helicopters are easier to use than fixed-wing aircraft if you need distance data, using a modification of the perpendicular distance method.

Using helicopters. Usable data can be collected from smaller helicopters if one or both doors of the helicopter are removed and some sort of sighting device provided that allows an observer to estimate distances out to sighting points detected out from the flight path. A relatively simple device is a light, rigid bar attached to the aircraft's undercarriage and extending horizontally for several metres out to one or both sides of the helicopter. Either one or two observers are then needed. A suitable rod is shown fitted to one side of two different helicopter models in Figure 30.

Figure 30. A sighting rod fitted to a small helicopter, the 'Hughes 300' *(left)* and to a medium-sized helicopter, a 'Bell Jet Ranger' *(right)*. The rod is color-banded in strips of equal width. The observer sits, with shoulder-belts attached, and leans slightly out of the aircraft so that it is possible to look directly down as well as to the side. In many countries attachment of a sighting rod is considered an engineering modification that also requires flight-testing before its use can be approved.

As the aircraft moves forward, to the observer the sighting rod seems to sweep over a series of bands on the ground parallel to the flight path. The rod provides a line of reference for observations. With this arrangement, color bands on the rod of equal width but different colors delineate strips of equal width on the ground. The observer's view of the ground is shown in Figure 31 on the next page. He or she notes the numbers and the relevant belt colour for animals on the ground as the rod appears to sweep over them, and ignores those that appear to be past the end of the rod. The width of the belts swept out on the ground below can be worked out trigonometrically if the working altitude of the aircraft and the observer's eyelevel distance above the rod are known.

Both taking observations and preparing the data input file require some changes to the procedure for ground observations. Key differences are these:

- *Flight paths.* To locate and follow a flight path as intended, especially in windy conditions, the aircraft should be equipped with a global positioning system (GPS) and the starting and finishing coordinates entered . A flight plan should be supplied to the pilot.

- *Logistics.* The range of a helicopter is limited. You may have to pre-arrange refueling points in the field with drums of suitable fuel, and take great pains to keep the fuel free of contamination.

- *Time of day.* In inland areas where most aerial surveys are conducted, large terrestrial herbivores are most easily detected from the air within the first 4 hours from dawn or the 3 hours or so before dusk, when animals are more likely to be out in the open. These are usually the best times for an aerial survey. The atmosphere is then usually more stable as well.

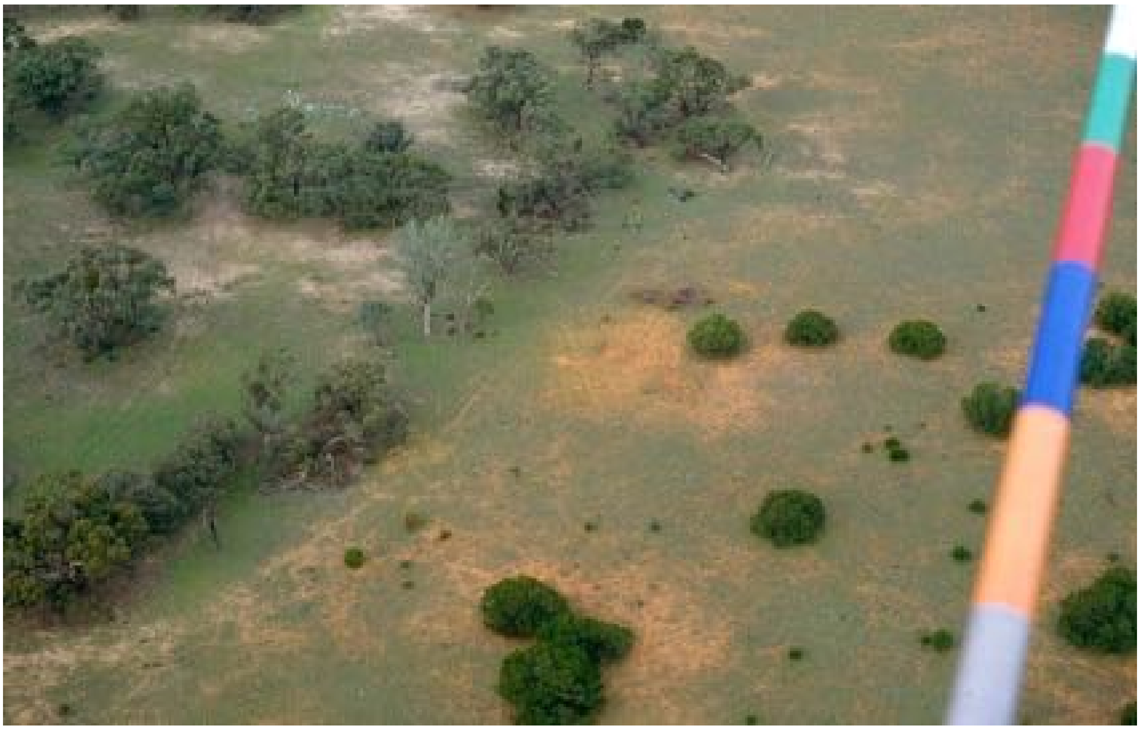


Figure 31. Part of an observer's view of the ground from the open side of a helicopter fitted with a color-banded horizontal sighting rod. Animals on the ground are recorded in their original positions as the rod sweeps over them, and recorded in the form: 'blue: 4', 'green: 1', 'grey: 2', 'blue: 1', and so on. Animals that take fright and have started to run when the observer first detects them present a problem (see text).

◆ *Altitude.* Density estimation requires that the aircraft maintains a relatively constant and accurately-known height above ground; this can be difficult for a pilot to maintain over uneven topography. An in-board radar altimeter is extremely helpful (though smaller helicopters are often not fitted with them). If only an aneroid altimeter is fitted, be aware that its readings will vary not only with altitude but also if the atmospheric pressure changes; An aneroid altimeter therefore needs to be re-calibrated from time to time during a survey if there is any possibility that air pressure is changing. A few pilots are expert at maintaining the correct height by 'dead reckoning', though it is unwise to rely on this. If the planned altitude is not maintained, density estimates will be biased.

◆ *Recording data.* The detection point of an animal group is recorded as a coloured band on the sighting rod appears to pass over it. A convenient way of doing this is for the observer to announce the beginning and end of each transect and every individual detection aloud, *e.g.* 'blue: 4', 'white: 3' and so on, recording these on a digital recorder or even a smartphone recorder app. Use a recorder that operates continuously throughout the flight (not a voice-activated one, which tends to cut in *during* the first syllable, often making it unintelligible). Each time the habitat changes, speak the habitat change too. (Durations of each section can be worked out later by timing the intervals between habitat changes in the recording.)

◆ *Fleeing animals.* Animals startled by the approaching aircraft have often started to move by the time an observer sees them. The observer needs to become familiar enough with the animal's behaviour when startled to judge where the animal was before it started to move; this requires practice and good judgement.

- ◆ *Collating data.* After a flight, data can be converted to the standard form. You can, for example, work out the approximate perpendicular distance outwards from immediately below you on the flight path to the centre of the strip on the ground subtended by each colored band; 'blue: 4' can then become, for instance, '4 at 74m'. There will be an upper limit to the distances, which will be the maximum class boundary distance subtended on the ground by the end of the sighting rod.

- ◆ *Entering data.* Completing the data input file requires some care because there are several important differences from the typical ground data entry procedure described in Chapter 8. (1) The data are perpendicular, pre-calculated distances. (2) Data are from a limited distance range. (3) The population movement rate can be set at 0 (because flight speed is relatively high). (4) Elevation distance is essentially the altitude difference. (5) Topography is usually treated as level. (6) Observations will be distances and clustedr sizes. (7) Class interval will be the strip width that each coloured band on the rod sweeps out on the ground below. (8) You may need to routinely preset the conspicuousness coefficient to a suitable value by setting its initial step size at 0 and (9) also decide on and enter an approximate maximum recognition distance.

- ◆ *Interpreting output.* Results can be interpreted as for other *WildlifeDensity* output.

With care, experience and a suitable habitat and species population, helicopter-based surveys can often provide usable density estimates. In some situations they can even be considerably cheaper than trying to achieve the same result with teams of paid observers on the ground.

Using fixed-wing aircraft. Some high-wing monoplanes, such as the 'Cessna 182', have been used for many years in aerial surveys of large herbivores and other conspicuous animals. Researchers use either carefully-delineated individual belt transects of known overall area or undefined belts of uncertain area out from the aircraft. While it is *possible* to collect distance data from such aircraft, either the aircraft itself requires some modification to overcome the complex three-dimensional geometry of the field of view, or the model used to make the density estimate needs to be tailored to that geometry. *WildlifeDensity,* as currently written, does not include such an algorithm.

Special-purpose aerial surveys. Twin-engined fixed-wing aircraft have been used successfully in some special situations, such as surveys of surfacing tuna schools in a calm sea in appropriate weather conditions. Such schools may be detectable at distances more than 30 km from an aircraft and are often sufficiently well-spaced to enable location and automatic recording of sighting and detection points by GPS, and subsequent density estimation.

When — and when not — to use *WildlifeDensity*

Will a line transect or fixed point survey, together with *WildlifeDensity,* be appropriate for a population survey you are contemplating? Will the density estimates be accurate and precise? Or will it let you down? Chapter 1 of this Guide set out a number of key assumptions you need to meet for line transect and fixed point modelling to achieve reliable density estimates. This final section of the *Guide* sets out a number of assumptions made either explicitly or implicitly in relation to those techniques, and makes some suggestions about survey situations which may or may not work with the technique you are contemplating. Use this as a checklist before beginning a new survey.

Can the technique work? First of all, using WildlifeDensity to estimate densities is not worth the time unless your density estimates are acceptably accurate and precise. Table 6 below compares some known density, estimates with those made by *WildlifeDensity* and the well-known perpendicular distance estimator *Distance*.

Table 6. Sample implementations of *Distance* and *WildlifeDensity* using line transect data in situations where the true population density was known from other studies. Both programs are capable of producing accurate and relatively precise estimates of population density provided that the data are collected appropriately — *i.e.*, in ways that enabled key assumptions of the programs to be met. Estimates are ± 1 standard error.

Data source	Survey type	No. of detections	Known density (ha^{-1})	*Distance* estimate (ha^{-1})	*WildlifeDensity estimate* (ha^{-1})
Laake's stakes, Logan Utah (Burnham et al 1980)	ground, perpendicular distance	68	**37.5**	36.1± 4.3	39.8 ± 6.8
numbered tree tags (Wischusen 2002)	ground, radial ground, perp.	1397	**14.5**	n/a 13.6 ± 1.1	14.8 ± 0..4 14.3 ± 0.3
red kangaroo, A.C.T. (Southwell 1994)	ground, radial ground, perp.	242	**2.2**	n/a 2.1 ± 0.1	2.4 ± 0.2 2.1 ± 0.2
western grey kangaroo, Hattah-Kulkyne 2006	ground, radial ground, perp.	55	**n/a**	14.2 ± 2.8	14.4 ± 1.5 12.5 ± 1.9
red kangaroo, Hattah-Kulkyne 2006	ground, radial ground, perp.	31	**n/a**	5.4 ± 1.8	5.5 ± 0.7 5.1 ± 0.6
koala, Strathbogie Ra., Vic.	vegetation belts, perp. (restricted)	27	**0.7**	n/a	0.6 ± 0.2

In many other surveys where the overall density remained unknown, the density estimates by *WildlifeDensity* and *Distance* have been similar. However this is less true of their standard errors. Where perpendicular distance data have been used with both estimators, the standard errors have tended to be similar. But, where standard errors estimated from radial and perpendicular data have been compared, the errors from radial data have usually been smaller (*i.e.* more precise). That reason alone, apart from any others, supports the use of line transect density estimation using radial distance data and program *WildlifeDensity* for suitable wildlife surveys.

Suitable species. The techniques described in this manual do not suit all species and survey situations. Species surveyed by distance sampling need to meet several criteria:

- *Conspicuousness:* be large enough and conspicuous enough to be detected readily by the average alert observer when in their normal habitats at distances of up to 10m (very small species, those that are very well camouflaged or hide from an observer being unsuitable);

◆ *Activity:* be active at the time of day of the survey (not asleep then, or torpid) and, in the case of fixed point surveys, be moving about continually;

◆ *Movement directions:* move about in random directions in relation to the observer during the survey (not favouring a particular direction, such as right to left on migration, for example);

◆ *Response to an observer:* be dispersed independently of the observer at the moment of detection (esp. not deliberately moving away from or towards an approaching observer in response to their approach before detection).

◆ *Clustering:* where a species normally lives in groups, the group sizes should not be very large in relation to the total number of individuals detected (e.g. a species found in the study area in, say, only very few, very large clusters); and

◆ *Abundance:* individuals and clusters should be sufficiently abundant to produce, within the total survey time available, a frequency distribution of detection distances large enough for effective modelling (uncommon species in the area being unsuitable).

Suitable study areas. Not all potential line transect or fixed point survey locations are usable with these techniques. Suitable study areas:

◆ *A 'broad-scale' survey situation:* should be of such a size and shape that detections are possible within a habitat type in any direction ahead up to or close to the maximum recognition distance for the species concerned, i.e. the patches of habitat are large enough to run a transect through it or locate a sampling point with habitat all around (unsuitable study areas including ponds and small lakes, elongated narrow areas such as rivers and streams, riparian strips, beaches and coastal mud-flats);

◆ *Ready observer access:* should have vegetation that enables observers to move quietly and inconspicuously as they observe (precluding habitats with vegetation so dense it must be 'crashed through' or otherwise traversed noisily during a transect or while reaching a sampling point) — unless a narrow, slightly-winding access route is cleared beforehand; and

◆ *Safety:* should provide operating conditions relatively safe from wildfires, attack by dangerous wildlife or local bandit or insurgent groups, so survey staff can concentrate on the task at hand.

Number of observations. As always, you need a sample size — the number of separate detections made in the field — large enough for you to estimate population parameters with confidence. Experience with *WildlifeDensity* shows that the number of detection events you need depends on the extent to which the population is grouped, how varied the groups are in size, how mobile the population is, and on whether you are using radial or perpendicular distance measurements for the analysis.

If separate, single observations are typical of your survey, you can sometimes get relatively precise density estimates (CV<20%) using radial distance data with as few as 15 detections, although 40 or more is preferred. With typically grouped animals, you may need 100 or more separate observations, and more with animals always on the move. If you intend to rely on perpendicular distance measurements in your analyses, you may need to increase sample sizes still further.

If you want reliable estimates of conspicuousness and cover for any reason, use radial rather than perpendicular distance measurements in your analyses, and make sure you have several hundred separate observations in your dataset. If large numbers of detections are out of the question, remember that these two parameters have opposite effects on detectability. They tend to vary together during computer searches for a minimum value with comparatively little effect on either detectability or the density estimate. The general detectability coefficient (*S*), in contrast, in relatively precise: it can sometimes achieve a 20% CV from as few as 20 samples.

Survey personnel. The personnel used for any survey work of this type need several attributes:

- *Motivation:* to be sufficiently motivated to want to learn the skills required and concentrate on the task at hand throughout a survey;
- *Physical abilities:* observers need very good eyesight, recorders need excellent record-keeping abilities, and all survey personnel should have the endurance to complete the task;
- *Training:* to be well-trained in the skills needed beforehand, and relatively (or absolutely) error-free during the survey itself.

Weather conditions. Because some more extreme weather conditions can significantly affect detectability, it is better not to carry out a survey if any of the following weather conditions are present: strong gusty winds, fog, heavy rain, hail, snowfalls, or thunderstorms.

Population dispersion. Populations dispersed so high above observer eyelevel that they cannot be seen and detected readily (e.g. small birds within the canopy foliage of very tall trees, or in the upper canopy of dense rain-forests) cannot readily be estimated using line transect methods (though their estimation may be possible with a fixed point technique in some circumstances).

An important comment. This manual has focused on line transect and fixed point sampling techniques for larger mammals and many birds, usually in terrestrial habitats (and sometimes also at the surface of the open sea). If you must have fairly precise estimates of population sizes, and you can't achieve this satisfactorily using the approaches described in this *Guide*, you will either have to look to other survey methods or evaluate whether or not density and, in turn, population estimates are really necessary and achievable with the resources you have.

APPENDICES

Appendix A:
the Mathematical Models

Appendix A describes how *WildlifeDensity* models detection-making in a uniform survey situation.

Modelling the Survey Situation.

Picture an observer attempting to sample the numbers of a bird or mammal species by sight in a land habitat. Let the overall density of that population be *D* individuals per unit area, dispersed in a roughly horizontal plane that averages *h* metres above or below observer eye level. The observer either looks out for animals ahead as he or she moves forward along a line transect or in all directions around them if they are at a fixed observing point. Suppose that, once an individual or group of animals is detected, the observer counts the number at the detection point and measures the horizontal distance *r* between observer and detection point. Suppose too that, once animals have been detected, they are not counted again unless again they move away and then return as a result of their own movements to be detected a second time. Thus, once seen, most individuals are effectively 'removed' from the sampled population.

The concept of observing arcs. Assume that detections are equally likely in any direction ahead of the observer. Visualise the observer effectively at the centre of a semi-circular or circular *observing (or scanning) arc* of radius *r (see Figure 32).* The arc moves forward when the observer moves forward in the case of line transects but is static if the observer is stationed at an observing point. Picture a detection being made in a representative plot of unit area at the horizontal distance *r*. An animal is detected at *r* when the observing arc moves over it or the animal moves through it as a result of its own movements. Suppose the perimeter of the arc has a finite but very narrow width *Δr.*

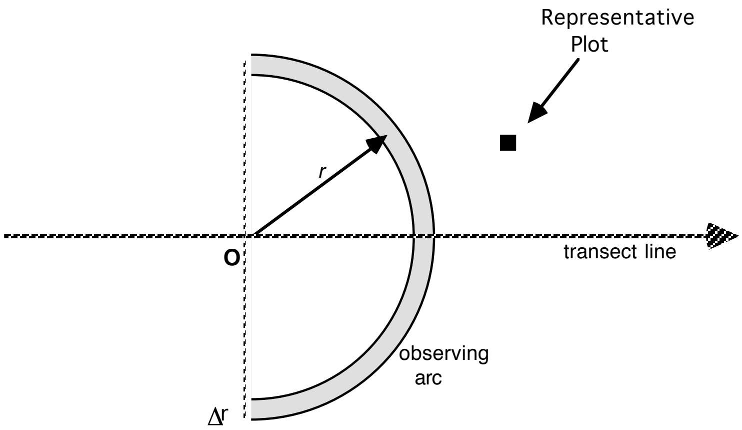


Figure 32. The concept of an observing arc for a line transect: the area in which an observer travelling a line transect detects animals at a radial distance *r* ahead. An animal present within a representative plot of unit area at a distance *r* from the observer may (or may not) be detected when crossed by the narrow arc of radius *r* and width *Δr.*

Detection distances. Consider an animal detected at a radial horizontal distance r and an approximate height difference h above or below the observer. (This is usually a convenient approximation although not all animals will be precisely within the plane.) The direct-line distance d to the animal can be calculated as $d = \sqrt{(r^2 + h^2)}$ *(Figure 33)*.

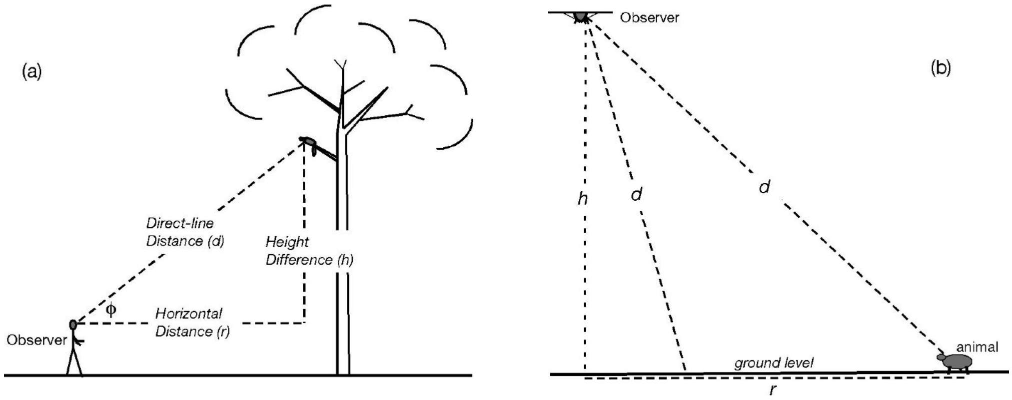


Figure 33. The sampling situation where the observer is h units above or below the plane occupied by the animals. (a) The ground survey situation. (b) The aerial survey situation. At the moment of detection, the observer is at a 'map' distance r from the animal in a horizontal plane, and at a direct-line distance d from the animal. This distance is given by the expression $d = (r^2 + h^2)$.

The line transect situation. Consider the line transect situation. When an observer walks a line transect, a very large number of arcs with radii from 0 to a maximum recognition distance (r_{max} and d_{max}) can be envisaged moving ahead with the observer *(Figure 34)*. If the arc width Δr is small enough to approach *zero*, the number of such arcs approaches infinity.

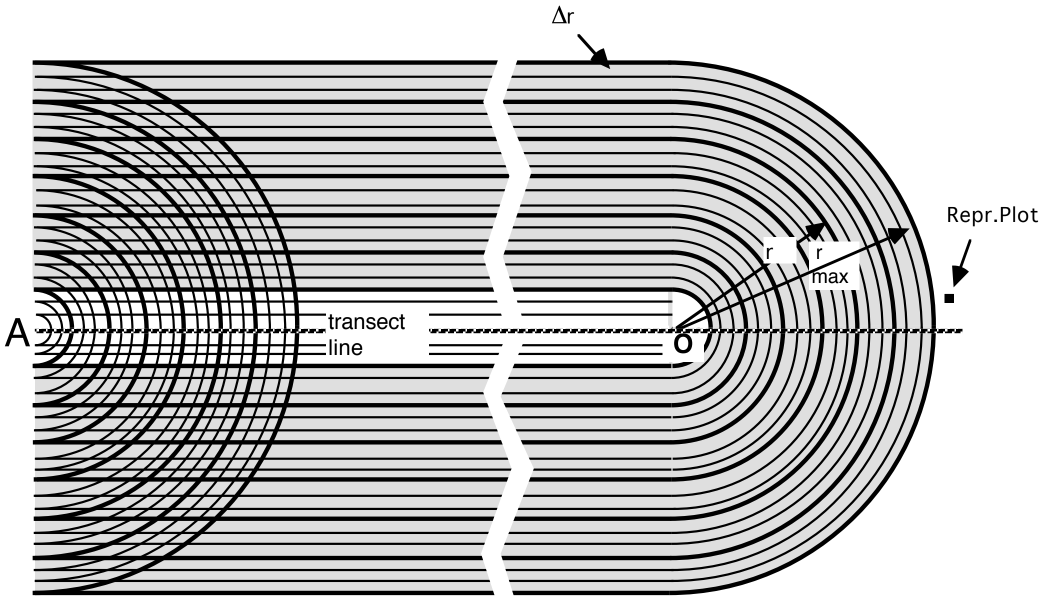


Figure 34. The line transect situation. Suppose an observer (O) in a given sampling situation is capable of detecting animals at any radial distance r between r_{min} and r_{max}. As he or she moves forward, a series of observing arcs, each of finite (but very narrow) width Δr and median radius r ($r_{min} \leq r \leq r_{max}$), can be pictured moving forward with them. (In practice there will be many such arcs, all very close together if Δr is very small.) A representative plot of unit area, containing animals at the population mean density D, lies ahead of the observer at a perpendicular distance y from the transect line. For the time being, consider only what will be detected in that plot.

For a transect of overall length L, each observing arc sweeps out a total area L units long and either r or $2r$ units wide, depending on whether observations are made on one or both sides of the transect. (*I.e.* area swept out = rL or $2rL$). The greater the distance r, the greater is the area swept out.

Cover and topography. Suppose there is relatively uniform (though heterogeneous on a micro scale) amount of lateral vegetation cover between the observer and animals in the population, represented by a vegetation cover proportion c_V $(0<c_V<1)$. Suppose too that there is a consistent unevenness in the topography, represented by a topographical cover value c_t $(0<c_t<1)$.

The probability of detecting an individual at r. Consider now an individual animal present within a narrow arc at a horizontal, radial distance r from the observer. Visual detection involves the observer detecting and recognising light patterns reflected from the animal to the observer. How detectable it is there will depend in part on its direct-line distance d. Assume that light from the animal undergoes both spherical spreading and also transmission losses due to properties of the atmosphere, vegetation and topography between animal and observer. Let its visual conspicuousness to the observer in that particular situation be represented by a conspicuousness coefficient 'a'. The amount of light it reflects is both related to the direct-line distance d by an inverse square relationship and also attenuated (progressively reduced) in proportion to the distance between animal and observer. Suppose too that the effect of topography begins at some minimum distance d_{tmin} from the observer.

Assume that detectability is constant across a narrow observing arc of median radius r and width Δr. The probability $g(r)$ of detecting that animal by sight within the arc at radial distance r, given its presence there, can then be modelled by **Equation 2**, *viz.*:

$$g(r) = a^2 \left(\frac{e^{-bd}(1-c_v)^{d} \cdot e^{c_T(d-d_T)}}{d^2} - \frac{e^{-bd_{\max}}(1-c_v)^{d_{\max}} \cdot e^{c_T(d_{\max}-d_T)}}{{d_{\max}}^2} \right) \qquad [Equation\,2]$$

where

- $g(r)$ = the probability that an observer will detect by sight an animal present at a horizontal radial distance r and a direct-line distance d;
- a = a conspicuousness coefficient for the species under survey conditions
- b = a mean attenuation coefficient for light travelling through the atmosphere from animal to observer under the survey conditions;
- c_V = the mean lateral vegetation cover in a direct line between an observer's eyes and the detection points of the targeted population ;
- c_T = the topographical cover value, an index of the mean rate of visibility decline due to topography in uneven landscape $(0 < c_T < 1)$;
- d = the direct-line distance between the observer's eyes and a detection point, where $d = r/\cos\phi$ and ϕ is the angle of elevation;
- d_{max} = the maximum direct-line recognition distance between the target species and an observer;
- d_T = in uneven landscape, the approximate direct-line distance ahead of an observer at which targeted individuals begin to be hidden by topographical features such as a ridge or hilltop $(d_t < d < d_{max})$; and

all distances are measured in metres.

The function *g(r)* can take any value between *0* (at the maximum recognition distance) and 1, but can't have any real value greater than 1 in the system described. Its form is shown in Figure 1 on p.14. If the atmosphere is clear, or tree and shrub cover is negligible, or topography is level, Equation 1 can be simplified by omitting the relevant term (which will approach 1 as the related coefficient approaches zero.)

The probability of individual presence at r. Notice in Figure 34 that the outermost observing arc will be the first to pass through the habitat ahead. It will be sampling a population that potentially has all its individuals available to be observed, and is at an overall density *D*. This corresponds to an average of *D* individuals in a representative plot one square metre in area. Every successive arc after that will be sweeping through an area that contains progressively fewer observable animals because each time animals are detected in arcs further out they are 'removed' from the population. Observing arcs very close to the observer are left with relatively few animals still undetected. Ultimately, as the horizontal distance r approaches 0, most or all animals ahead of the observer will have been detected. The chance of detecting an animal at *r* therefore depends not only on the probability of detecting the animal at that distance (given that it was present in the first place) ***but on the probability that the animal has not yet been seen and is still there, as yet unobserved.***

It can be shown that the probability *Q(r)* that any individual is still present and available to be observed at *r,* after some individuals at greater distances have already been detected and then disregarded, can be modelled by **Equation 3.** *viz.:*

$$Q(r) = \prod_{i=1}^{n_r} [1 - g(r_{\max} - (i-1) \cdot \Delta r)] \qquad [Equation\ 3]$$

where *Q(r)* = the probability that an original animal is still present undetected in a representative area after observing arcs with greater values of *r* have passed over it, where $0<r<r_{max}$ and $Q(r) = 1$ at $r \geq r_{max}$;

Π = a product of a set of terms;

i = position index, *i.e.* the *i*th term in a series that begins with $r = r_{max}$

r_{max} = the maximum radial detection distance ;

Δr = the scanning (observing) arc width used internally by the program ; and

n_r = $(r_{max} - r) / \Delta r$, the number of scanning arcs or strips from r_{max} to radial distance *r*..

The probability of both presence and detection at r. At a representative r value within the *n*th observing arc, the probability of both detection and presence *P(d)* at any radial distance r ($r_{min}<r\ r_{max}$) is given by **Equation 4**, viz:

$$P_d = g(r) \cdot Q(r_{n-1}) \qquad [Equation\ 4]$$

Note that each *Q(r)* value is computed using data from the preceding *(n-1)*th scanning arc.

Figure 35 shows the relationships between the probability of detection *P(r),* given presence, the probability *Q(r)* an individual is still likely to be present, and the probability density function over a range

of horizontal radial distances from close to the maximum recognition distance r_{max} back to the minimum distance r_{min} by which all individuals will have been detected. The graph is based on a real example: a honeyeater population about 7.5 m above observer eye level in a riparian open woodland community in south-eastern Australia. (Note when reading this graph that its horizontal axis reads from right to left.) The p.d.f. (red curve) is typical of a radial detection distance distribution.

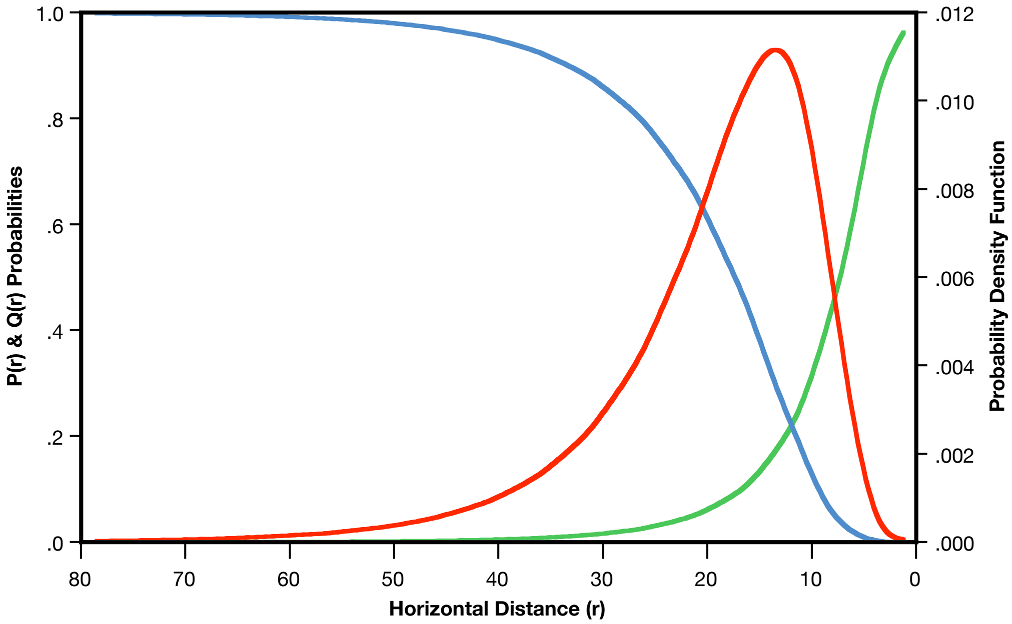


Figure 35. The relationships between the probability density function *(red line)*, the probability of detection *(green line) and* the proportion of the population still undetected *(blue line)* over an 80 m range of distances, from near the maximum observing distance *(at left)* to the observer's position *(at right).* The p.d.f. and the other probabilities are on different scales and the x-axis is reversed. Starting at the maximum recognition distance (>80m), the p.d.f. rises to a maximum as the observer approaches, then declines to zero near the observer. The p.d.f. is typically bell-shaped and skewed to one side. (To visualise what happens on a transect, follow each curve from left to right.)

This probability density function in Equation 4 is likely to apply whichever distance sampling data type the investigator intends to use (radial or fixed point detection distances from the observer, or perpendicular distances from the transect line—*see below*.

The number of detections at r. The situations considered so far have examined the likelihood that an individual animal is both present and detected at *r* In the survey situation described. Suppose there were initially a mean *D* individuals per unit area in the habitat concerned. Let p_a be the proportion of the population visible to an observer (i.e. not hidden in burrows, tree hollows, etc.); in most sampling situations p_a will be 1. Assume too for the moment that the population is immobile. The total number we expect to be detected at *r*, *E[N],* will then be the product of the p.d.f., the area swept out, the density of the population and the proportion of the population visible to the observer.

The effects of animal mobility. Most bird and mammal populations targeted in surveys are not immobile: they show continual changes in position as they forage and undertake other normal activities. As shown in Figure 18 on p.45, the effect of horizontal movement (displacement) by animals in the

population is to increase the numbers detected in line transects. The extent depends on the travelling speed of the observer. The effect is greatest at slow observer rates of travel and least at high rates.

Let *J* be ***a movement correction factor***, representing the ratio of the number of contacts between an observer and a population at the average animal movement rates during a survey and the expected contact number had the population been immobile instead.

$$J = \frac{no.\,of\ contacts\ at\ overall\ animal\ speed\ u\ and\ observer\ speed\ w}{no.\,of\ contacts\ if\ animal\ speed\ is\ zero}$$

Animal mobility thus has an effect on the numbers observed comparable to lengthening the transect from a length *L* to a length *LJ.*

The mathematical expression developed to model this ratio depends on the relative velocities of observer and animals. Its derivation is relatively complex and will not be described here. However *J* can be approximated by the expressions shown in **Equations 1a** and **1b** below. For animal movement rates less than 5 times the observer's rate of travel,

$$J = 1.0051 - 0.0213u/w + 0.000287u^2/w^2 + 0.2791u^3/w^3 - 0.1298u^4/w^4 + 0.02345u^5/w^5 - 0.001533u^6/w^6 \qquad [Equation\ 1a]$$

where u = mean population horizontal displacement rate in m/min;
w = mean observer horizontal displacement rate of travel in m/min.

For very rapid animal movement rates over 5 times the observer's travel rate,

$$J = 0.8183u/w \qquad [Equation\ 1b]$$

Calculating the expected number of detections at *r*, *E*[*N*]*,* will then involve using an effective transect length *LJ*, with *J* approximated either by Equation 1a or 1b. The expected numbers detected at a radial distance *r* from the observer and a comparable perpendicular distance *y* from the transect line will, however, be different.

The modelling process. Much of the *WildlifeDensity* program involves calculating the expected number of detections in each frequency class before comparing them with the numbers observed. *WildlifeDensity* initially arranges frequency data into classes based on detection distances of pre-determined width. Beginning with the most distant class, each class is then subdivided by the program into observing (or scanning) arcs. These are seen as having moved forward with the observer along the entire length of the transect(s). As that occurs, each arc sweeps out a long rectangle the length of the transect(s); the rectangles are of varying width in radial distance-based analyses and uniform width in the perpendicular case.

The way that expected numbers are calculated is similar in principle whether the original sampling data are radial transect data, perpendicular transect data, or radial data from fixed observing points. However the precise models used differ between them because the geometries of the three types of sampling situation are different.

Whichever the type of sampling situation, the probability of detection at any radial distance r, given presence, is given by Equation 2. It varies from g(r) = 1 at r_{max} to 0 at r_{min}. The probability that an individual is still present and undetected there, *Q(r)*, is a function of the number of arcs between r_{max}

and r and the probabilities of detection in each. Its value is given by Equation 3, where n = [(r_{max} - r) / Δr]. *Q(r)* varies from *Q(r)* = 1 at r_{max} to 0 at r_{min}.

For each type of sampling situation, consider what happens within a representative sampling class, shown shaded in Figures 36 and 38. Suppose each class has a width *W* and is subdivided into *n* subclasses (arcs) each of width Δr (so that $W = n \cdot \Delta r$.). *WildlifeDensity* sets its own preprogrammed and relatively narrow arc width, with $\Delta r \approx W \cdot$ *(class no.)*/800.

Modelling Radial Distance Transect Data

The way the program is designed depends critically on how the survey area is sampled. Radial data are detection distances between the observer and the detection points. Suppose the scanning arcs used are the nested set of equally-spaced concentric half-circles shown in Figure 36 below.

Suppose a frequency distribution of horizontal radial detection distances is divided into $m \approx (r_{max} - r_{min})/W$ classes of equal width, where r_{max} and r_{min} are the outer and inner boundaries of the entire area covered and *W* is the preset class width. Let each class be subdivided into *n* semicircular observing arcs each Δr-wide centred on the observer. Each class begins at its furthest (outer edge) distance r_2, where $r_2 = r_{max} - (i - 1) * W$ and *i* the number of classes between r_{max} and r_2.

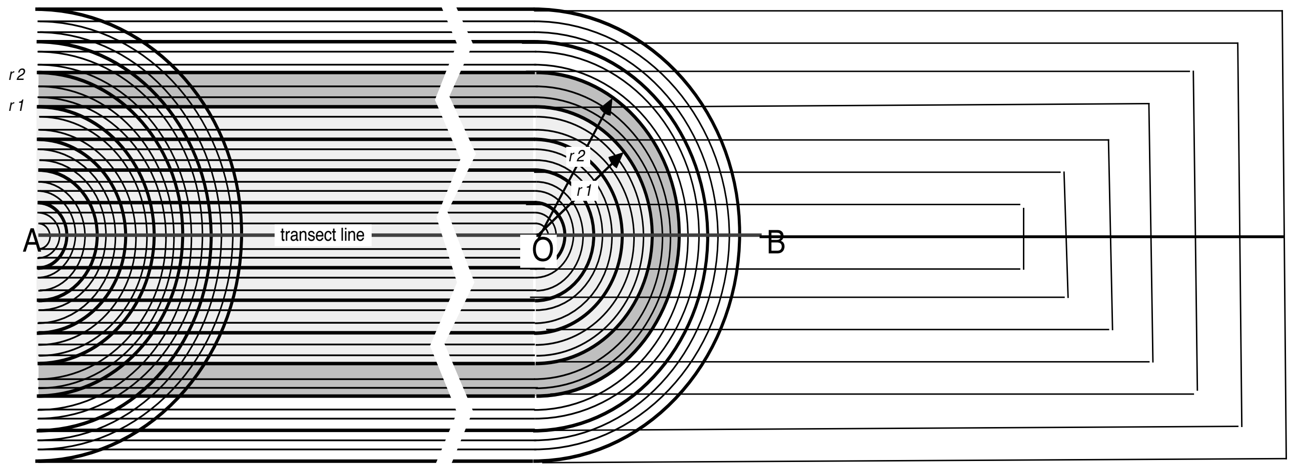


Figure 36. What happens on a line transect analysis using radial data. An observer travelling from Point A to Point O detects targeted animals as far away as r_{max}, the outer edge of the outermost arc. This is the starting point. Detection distance data are subdivided here into 7 classes, with 3 observing arcs in each class (separated by lines), making 21 arcs in all. (There are many more in practice.) As the observer moves from A to O, each arc sweeps out a rectangle that is eventually the length of the transect and has a width twice the distance between the observer and the outer edge of the arc (r_2). (Only the rectangles swept out by the classes are shown here.) Detections in each arc are made only between the inner and outer edges of that arc and so are unique to it, unlike the situation with perpendicular data (*next section*).

With radial distance measurements, for a distance class between two radial distances r_2 and r_1, the detections made in that range — and the detection probability g(r) values calculated — are unique to that range. However the probability of undetected presence *Q(r)* is initially 1 in the unsurveyed area ahead of the observer's maximum visual range. It then falls progressively from arc to arc from the maximum recognition distance r_{max} to the arc with the lowest r value in the current class. Hence,

Expected number in a single scanning arc

= (apparent number present) x (probability of presence and detection)

= [(apparent density) x (area sampled)] x [(probability of detection) x (probability of undetected presence)]

= [(D . J_k . $P_{a)}$) x (n_s . L . r)] x [(Δr . g(r)) x (Q(r))

= D J_k $P_{a)}$ n_s L r Δr g(r) Q(r)

The total number of animals expected within the range, *E*[*N*], will then be the grand total of the numbers encountered by the various observing arcs. *I.e.:*

$$E[N] = \sum(no.\ detected\ by\ each\ arc\ in\ the\ class]$$

The radial distance line transect model. If we are to represent what happens in the field, where the outermost arc in a class sweeps out the area ahead, followed in turn by all other arcs in the class going inward, our mathematical model should do the same. For any frequency class between two radial distances r_2 and r_1 of an observer, where r_{max} is the outer boundary of the outermost observing arc in the entire series and r_h the outer margin of the first arc in the class, the expected total number of detections *E[N]* within a class can be predicted by ***Equation 5***, *viz*:

$$E[N] = D\,J\,p_a\,n_s\,L\,\Delta r \sum_{i=1}^{n} \{r_h - (i-1)\,\Delta r\} \cdot g\{r-(i-1)\,\Delta r\} \cdot Q\{r-(i-2)\,\Delta r\}$$

[*Equation 5*]

where

E[N] = expected number of detections in a radial distance class between distances r_2 and r_1 ahead of an observer;

D = overall mean density (in m^{-2}) of the targeted population in the entire survey area, i.e. mean number in a sample plot of area 1 m^2 ($0 < D < \infty$);

J = expected ratio of the number of 'contacts' (detections) between a mobile population moving in random directions in a horizontal plane at mean rate u (m/min) and an observer travelling a line transect through the area at a rate w (m/min), and the number of contacts expected if the population were stationary with only the observer moving ($1 < J < 0.8183u/w$) — and calculated by Equation 1a or 1b;

p_a = proportion of the targeted population observable during a survey and not hidden from view in tree hollows, burrows, nests etc. ($0 < P_a < 1$) ;

n_s = number of transect sides scanned by an observer during a line transect survey (1 or 2, usually 2) ;

L = total transect length ;

W = class interval width ;

C = no. of classes in range = (r_{max} - r_{min}) / *W* ;

n = number of scanning arcs in a class, where $n_c \approx 800 / C$;

Δr = arc width used internally by the program in modelling the survey situation, where $\Delta r \approx W / n_c$;

i	=	position index for a scanning arc in the series that begins with the outermost ;
r_h	=	radial detection distance between observer and outer boundary of the current arc ;
r	=	radial distance from observer to arc centre ;
$g(r)$	=	probability that an observer will detect a targeted animal in the ith scanning arc at a horizontal radial distance r from the observer (from Equation 2) ; and
$Q(r)$	=	probability of previously undetected presence in the ith observing arc at radial distance r from the observer from Equation 3).

[The r values in Equation 5 apply only to arcs with radii that fall within the class interval concerned. However each area swept by these arcs has already been swept by arcs further out from the observer. Hence the associated $g(r)$ and $Q(r)$ values are calculated by using all the observing arcs with radii between r and r_{max} from the observer. Equation 5 should then model the frequency distributions of radial distance data for all situations in which the various assumptions that underlie the model (p.22) are met, provided that the targeted animals are sufficiently large to be readily detectable.]

A graph of the radial distance model. When Equation 5 is used to calculate a frequency distribution and plotted graphically, its form is as shown in Figure 37. (The data are the same honeyeater data used to derive Figure 35 earlier.) The graph has the typical right-skewed bell shape of a line transect frequency distribution of horizontal radial distances from an observer.

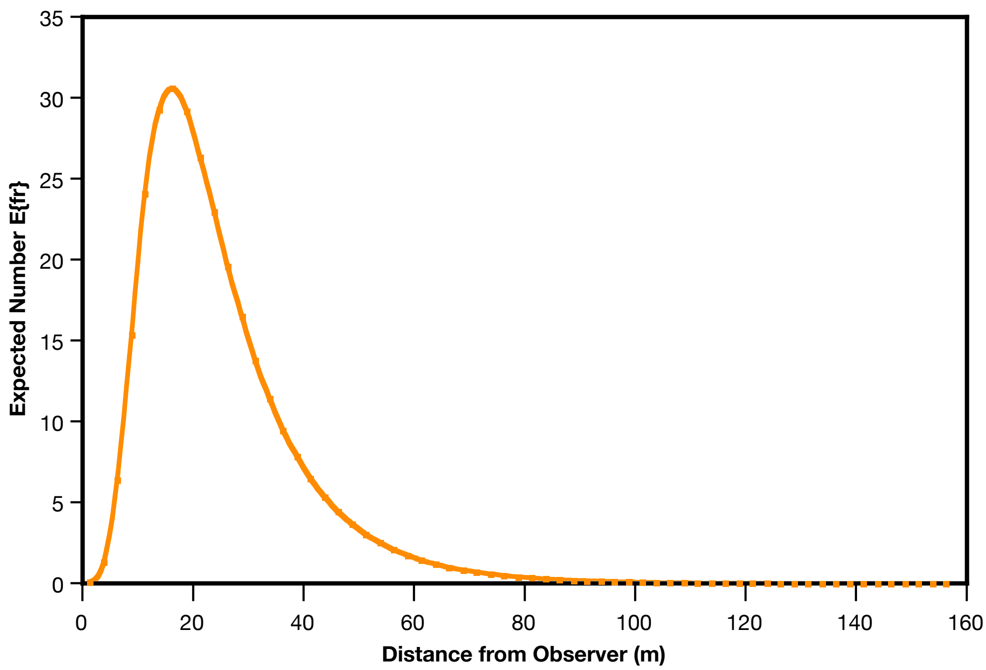


Figure 37. The shape of the radial distance model described by Equation 5, drawn using parameter values calculated from the same honeyeater population survey data as previously. (Density D = 2.3/ha; conspicuousness coefficient a = 9.03 m; cover proportion c_V = 0.057; maximum recognition distance r_{max} = 158.5 m; height difference h = 7.5 m; level topography.) The frequency distribution of the model closely fits the observed radial distance distribution (*see Fig.6 on p.15*).

Modelling Perpendicular Distance Transect Data

With perpendicular distance data, how the program's algorithms work again depends on how a survey area is sampled. Perpendicular data are distances between the detection points and the transect line, not the observer, usually calculated from the radial distance and lateral detection angle. The program then predicts detection numbers between any two detection distances y_2 and y_1 of the transect line. The geometry of that sampling situation then differs from a radial distance survey (see Figure 38). Although the areas swept out by the various observing arcs are again rectangular, this time each is only the width of the arc. All arcs are identical and relatively narrow. Also, each sample plot in the area covered is swept not only by the current observing arc but by every arc ahead of it. Once all the arcs have passed through it, it can include detections from *any* of those arcs.

Consider a distribution of horizontal, perpendicular detection distances *y* from a transect line (where $y = r \sin\theta$ and θ the lateral detection angle). Suppose it is divided into $m = (y_{max} - y_{min}) / W$ classes of equal width, where y_{max} and y_{min} are the outer and inner boundaries of the entire scanned area and *W* is the class width. (In a large sample the value of y_{max} approaches r_{max} and y_{min} approaches r_{min}.) Let each class be subdivided into *n* semicircular scanning arcs each Δr-wide centred on the observer. Beginning with the outermost arc (i = 1), that of greatest mean radius, its extreme ends each sweep out a rectangle *w* wide for the length of the transect *L* as the observer moves from start to end of a transect.

The next arc inward does the same. However part of the first arc has already swept through its rectangles, possibly resulting in detections and reducing the number remaining to be detected. The next arc repeats the process, adding in the effects of another arc, and so on. Each subsequent arc contributes to the number of detections and reduces the numbers present in all rectangles formed by arcs with lesser radii. These effects accumulate from arc to arc, beginning from the very first arc, where $r_h = r_{max} \approx y_{max}$. This effect is thus different from that with radial distance data, where observations within an arc contribute to expected numbers for that class only, and the rectangles swept out are wider. Here each perpendicular class and subclass except the first may include detections from both that category and those further out.

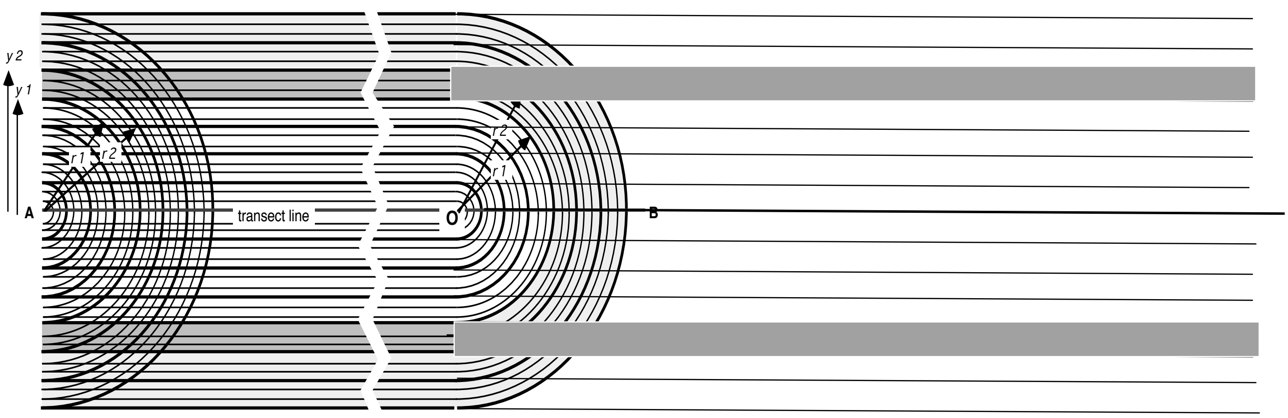


Figure 38. What happens on a line transect when perpendicular distances are used. Unlike the radial distance situation, these distances are measured from the transect. Focus now on the narrow parallel strips swept out by the extreme ends of each arc: 21 parallel strips are shown in the figure, each of which is the width of the arc and the length of the transect. Although each arc sweeps out the same area as shown in Figure 36 they are no longer independent. Each contributes detections to every scanned strip closer to the transect line.

Strip 1 — the outermost — draws only on detections from Arc 1. Strip 2 — the next inward — draws on detections made in Arcs 1 and 2; Strip 3 from Arcs 1-3; Strip 4 from Arcs 1-4, and so on right up to the innermost strip — Strip 21 — which draws from all the observing arcs in the series. Exactly the same set of observations are made as for radial analysis, but they are combined differently.

The number of detections expected within a *single* strip of width $w = \Delta r$ will be as follows:

Expected number in a strip

= *(apparent number present) x (probability of presence and detection)*

= *[(apparent density) x (area sampled)] x [(probability of detection) x (probability of undetected presence)]*

= *[(D . J . p_a)) x (n_s . L . w)] x [(w . g(r) x (Q(r)]*

= *D J p_a n_s L w Δr g(r) Q(r)*

The perpendicular distance line transect model. While the expected detection number in each strip is given by the equation above, the total detections expected between perpendicular distances y_1 and y_2 of the transect line will be the sum total of all such terms within the belt: the sum of a set of sums. It follows that, given *m* perpendicular distance classes, the total number of detections expected in the *l*th class between distances y_2 and y_1 from the transect line will be as given by ***Equation 6,*** *viz.*:

$$E[N] = D\,J\,p_a\,n_s\,L\,w\,\Delta r \sum_{j=1}^{m} \sum_{i=1}^{n} g\{r_{\max} - (j \cdot n - n - i)\,\Delta r\} \cdot Q\{r_{\max} + \Delta r - (j \cdot n - n - i)\,\Delta r\}$$

[*Equation 6*]

where *E[N]*= expected number of detections in the *j*th perpendicular distance class ;

w = width of each strip swept out by a scanning arc over the length of the transect(s) ;

m = number of distance classes in the entire area from y_{max} to y_{min} on each side of the transect line ;

j = an index of the position of each class in the entire series, beginning with the outermost ;

n = number of scanning strips (and arcs) within a class during program runs ;

i = an index of the position of each strip within a class, beginning with the outermost ;

g(r) is calculated using Equation 2 ;

Q(r) is calculated using Equation 3 ; and

the remaining terms are as defined earlier.

A graph of the perpendicular distance model. When Equation 6 is used to calculate a frequency distribution and plotted graphically, its form is as shown by Figure 39: a reversed sigmoid distribution. The data are the same honeyeater data as before.

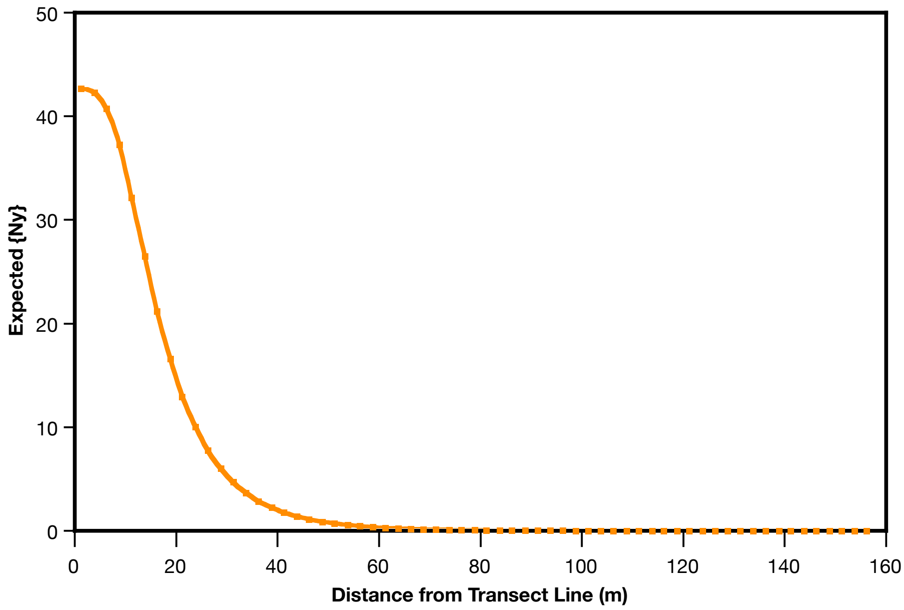


Figure 39. The shape of the perpendicular distance model in Equation 6, drawn using the same parameter values as Figure 37. The frequency distribution of the model is similar to observed perpendicular distance distributions (*see Fig.4 on p.16*).

Modelling Fixed Observing Point Data

Finally, consider a frequency distribution of horizontal, radial detection distances from an observer surveying a mobile population while slowly rotating for a period at a fixed observing point. Detections ('contacts') in this situation result from random translational movements towards the observer by members of that population.

Observing circles. A rotating observer can be thought of as being at the centre of a very large number of concentric *circular* observing arcs with radii that vary from close to 0m at the observer to the maximum recognition distance r_{max}. Observations take place over an allotted period of time t. The situation is more or less that shown in Figure 5 on p.17, except that in practice there are far more observing circles, each a very small distance Δr units apart. The individual animals in the population characteristically show movement in the horizontal plane at a variety of speeds and directions, and any animal up to the maximum direct-line recognition distance d_{max} is potentially detectable.

Picture an individual animal being detected as it crosses the perimeter of one of these circles *(Figure 40)*. Its horizontal radial detection distance r will be somewhere in the range $0 < r < r_{max}$. Let the relevant portion of the observing arc—the proportion of each circle scanned by the observer—be p_s $(0 < p_s < 1)$, and let the proportion of the total population potentially observable at the survey time be p_d $[0 < P_d < 1]$.

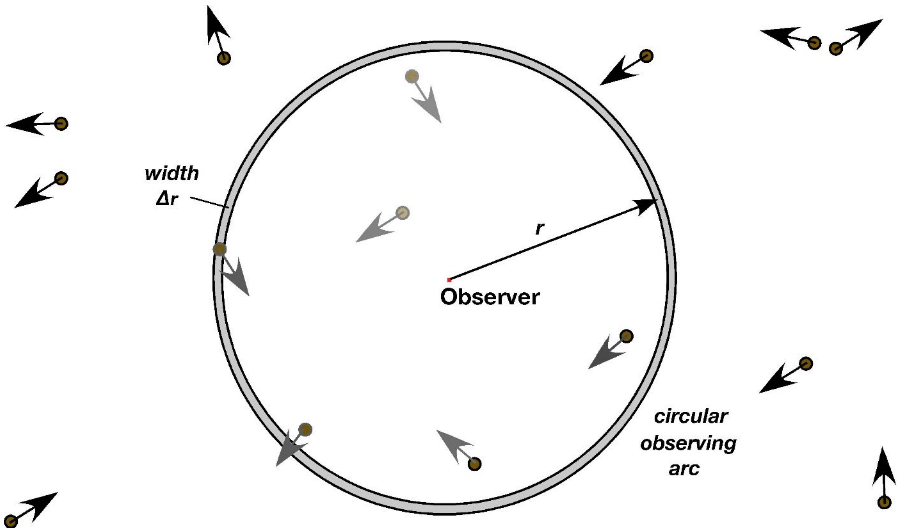


Figure 40. Visualise an observer at a fixed observation point at the centre of a horizontal, circular observing arc of radius *r*, with a perimeter of very narrow width *Δr.* The observer rotates continually so that detections in any direction are possible. Animals from the population in the vicinity move about in the horizontal plane in more or less random directions and at a variety of speeds $\hat{u}$. Any animal that crosses that arc *(e.g. at left)* has a probability of detection *g(r)* already described by Equation 1.

Number of contacts with a perimeter. Consider now the expected total number of contacts between individual animals and the perimeter of a single, circular observing arc of radius r. Suppose that an animal's movement is rectilinear: that is, it is made up a great many very short straight paths linked end-to-end with continual direction changes, and let a movement direction change in any direction be equally likely. At any instant, the movement speeds of animals ($\hat{u}$) in the population will vary between 0 and some maximum speed u_{max}. Let the mean animal movement speed be $\bar{u}$. The mean distance travelled by an animal in time *t* will then be $\bar{u}t$ units of distance. (If speeds are measured in m/min, and times in minutes, then the distances travelled will be in metres.)

At any moment, with animals moving in rectilinear paths, individual animals show a great variety of movement directions (*Figure 40*). But from any particular direction, only some individuals will cross an observing arc — those travelling directly towards its perimeter. Consider only those individuals coming directly towards the observing arc at right angles to a given arc diameter, and in parallel *(*as in *Figure 41* on the next page*, left side).*

Over a period of time *t*, those animals travelling in the appropriate direction at a mean speed $\bar{u}$ and sufficiently close to the perimeter are likely to cross it. Those that do will—on average—effectively come from the area shown in the right-hand diagram in Figure 41. Looking at this another way, animals that cross the perimeter from that direction effectively sweep out an area that corresponds to a rectangle as wide as the diameter of the observing arc (2r) and with a length $\bar{u}t$. Thus

$$\textit{Effective sampled area} = 2r\bar{u}t$$

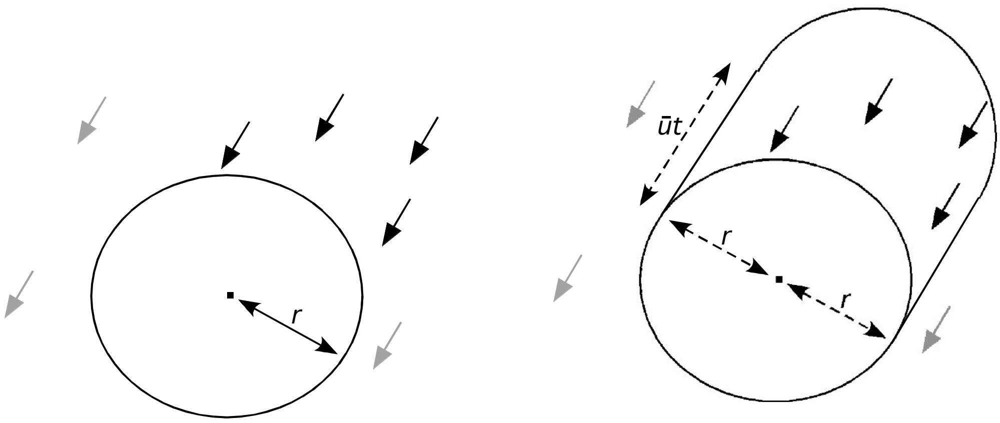


Figure 41. The diagram at left shows a single observing circle of radius r and negligible perimeter arc width, and a simplified representation of individual animals that are moving directly towards it. In the period of time t, some of these animals are likely to cross the observing arc. The right-hand diagram shows that the area from which those individuals come is, on average, equal to that of a rectangle ūt units long and 2r units wide; the animals effectively sweep out that area as they cross the arc.

Assume that, with random movement, movements from any direction are equally likely. The pattern shown in Figure 41 will apply to some animals close to the arc whatever their direction of origin. The total number of contacts in time *t* will be from all directions; and those coming from each direction will, on average, each sweep out the same area. The total number of contacts made with any particular observing arc will therefore be a function of the arc diameter *2r*, the average movement rate of the population $\bar{u}$, the time taken *t*, the mean density of the population, the probability of detection at that distance *g(r)* and the proportion of the population as yet undetected there.

Let the mean number of animals present in unit area before the survey begins be *D* individuals. For the outermost observing arc in a series *(Figure 42),* if the observer scans the full circle and we disregard detectability, the potential number of contacts with a particular observing circle from all directions in time *t* will be:

$$\textit{Potential total no. of contacts} = \textit{(mean density) x (area sampled)} = D.2r\bar{u}t$$

If only a proportion p_S of the perimeter is scanned, the number of potential contacts becomes:

$$\textit{Possible no. of contacts} = D2r\bar{u}t.p_S$$

and, if only a proportion p_a of the population is active at the time of a survey, the number of possible contacts will reduce still further to:

$$\textit{Possible no. of contacts} = D\ 2r\ \bar{u}t\ p_s\, p_a$$

The total fixed point observing situation—with a large number of concentric observing circles of perimeter width Δr surrounding the observer (Figure 42)—is closely analogous to the radial distance line transect situation already modelled in Equations 1-4. For a start, the presence of an animal crossing the perimeter of an observing circle does not of course mean it will be detected by the observer at the centre.

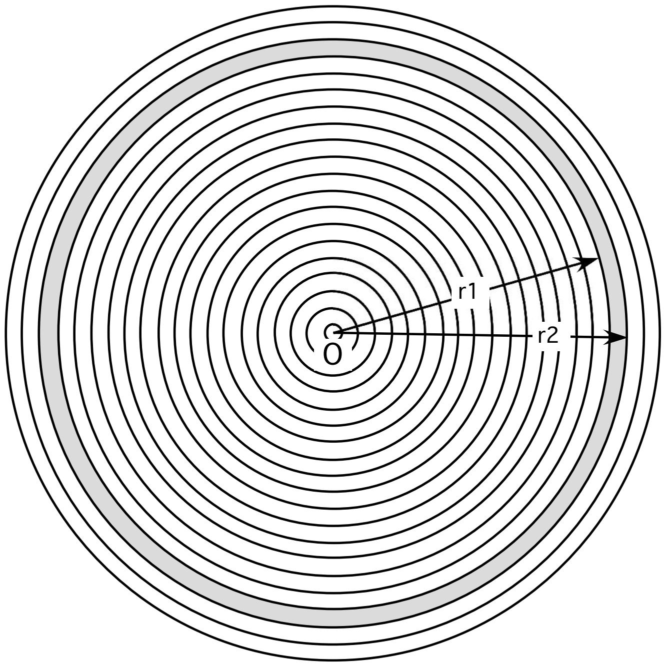


Figure 42. The fixed point sampling situation. An observer at Point O is surrounded by a very large number of concentric circular observing arcs, each of radius r, and *each* separated from the next by a very narrow observing arc of width *Δr*. Some animals in the general vicinity may, as a result of their intrinsic movement patterns, cross these from further out and move into the sampled area. As they cross a particular arc where they may or may not be detected, they effectively move through an area equivalent to a rectangle *2r* units wide and *ūt* units long. A detection distance class between r_1 and r_2 will contain a number of observing circles (only one arc per class is shown here).

As with line transects, the probability of detection *g(r)* at each observing arc will be a function of the direct-line distance to a detection point and the various parameters of the observing situation described earlier. Also, as is the case with line transects, some animals will already have been detected by observing arcs further out and effectively 'removed' from the population; the proportion that remains so far undetected will again be Q(r).

The expected number detected by the observer within a single narrow circular arc of width *Δr* at a median radial distance *r* therefore becomes:

$$\text{Expected number detected in arc} = 2\,D\,p_s\,p_a\,u\,t\,\Delta r\,r\,g(r)\,Q(r)$$

Suppose the whole fixed observing point distance distribution is divided into $m = (r_{max} - r_{min}) / W$ classes of equal width, where r_{max} and r_{min} are the outer and inner boundaries of the total scanned area and *W* is the class width. Let each class be subdivided into *n* observing (scanning) arcs, each circular in shape, resulting in a set of annular rings of decreasing radius r from r_{max} to r_{min}.

Modelling the expected number of contacts made in each class is then analogous to the situation with transects using radial data though structurally different. Picture a centrally-placed observer scanning around an observing point for a time *t* (in min) during which target animals are detected at a variety of distances. For a representative *l*th) class going inward from the outermost, we will consider the detections made by an observer as those population members that moved directly towards the observer in time *t* at a mean speed *u,* crossing the arc perimeter at a distance r_h as a result of that movement. They effectively come from a rectangular area the overall diameter of the observing arc $2r_h$ times a length *ut*, *i.e*. an area $2ut.r_h$.

Like a radial distance line transect survey, the total number of animals expected within the range, *E*[*N*], will then be the grand total of the numbers encountered by the various observing arcs. *I.e.*

$$E[N] = \sum(no.\ detected\ by\ each\ arc\ in\ the\ class]$$

The fixed point sampling model. It follows that the total number of fixed point detections, *E[N],* expected in the *i*th distance class will be given by ***Equation 7***, *viz.*:

$$E[N] = 2\,D\,p_s\,p_a\,u\,t\,\Delta r \sum_{i=1}^{n_a} \{r_h-(i-1)\Delta r\}\cdot g\{r-(i-1)\Delta r\}\cdot Q\{r-(i-2)\Delta r\}$$

[*Equation 7*]

where
- *E[N]* = the expected detection number in a fixed point distance class,;
- p_s = the proportion of a circle surrounding a sampling point scanned by observers during a survey from an observing point ;
- u = the mean horizontal displacement rate (m/min) of targeted population members under conditions comparable to those during the survey ;
- t = total time (in min) spent scanning around the observing points ;
- r_h = radial detection distance from the observing point to the outer boundary of a distance class ;
- *g(r)* = probability that an observer will detect a targeted animal in the ith observing arc at a horizontal radial distance r from the observer (from Equation 2) ;
- Q(r) = probability of previously undetected presence in the ith observing arc at radial distance r from the observer (from Equation 3);

with other terms as already defined.

Equation 7 should model the frequency distributions of fixed point sampling data for all situations in which the various assumptions underlying the model are met (*see p.22 on)* and the animals themselves are conspicuous enough to be readily detectable.

A graph of the fixed point sampling model. When Equation 7 is used to calculate a frequency distribution and this is plotted graphically, its shape is as shown by Figure 43: a bell-shaped curve generally skewed to the right. The graph is similar in form to those from line transect frequency distributions of radial distances (*Figure 37*). The data are from the same honeyeater population as previously but in this case collected using the fixed point technique.

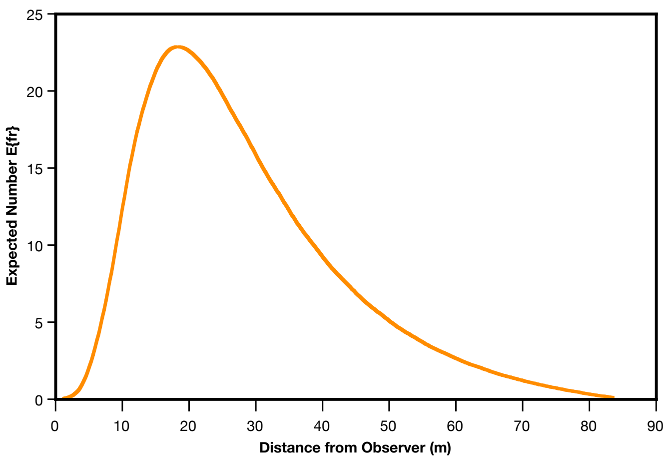


Figure 43. The shape of the fixed point survey model in Equation 7, based on data collected on the same honeyeater population as the graphs used for the line transect models. The frequency distribution of the model closely approximates the frequency distribution of field data *(see Fig. 6 on p.17)*.

How the *WildlifeDensity* program works

WildlifeDensity employs a curve-fitting process to compare the observed frequency distributions of detection distance data, subdivided into frequency classes, with an expected frequency distribution calculated using whichever of the three models above is appropriate. The intention behind each computer run is to find parameter values (population density, conspicuousness, cover) for which the overall difference between the observed and calculated numbers is minimal. The curve-fitting process uses a function-minimisation procedure based on Nelder and Mead's (1965) classic simplex method. Unlike many approaches in current use, the Nelder-Mead method does not rely on derivative algorithms of the model: instead it involves a direct search process. It has been widely used since, including commercial software packages such as MATLAB,. It owes its continuing popularity to its accuracy and efficiency in most circumstances (Lewis, Torczon & Trosset 2000; Price, Coupe & Byatt 2002), though it may fail in some situations (McKinnon 1998). The design of *WildlifeDensity* allows for unsuccessful searches should they occur.

Estimating parameter values. In an initial set of iterations, *WildlifeDensity* uses the original field data collated into classes of predetermined width. Predicted frequencies are first calculated for each distance class using parameter values supplied by the user. Comparisons between observed and predicted numbers are then made class by class. For each class, the predicted frequency is subtracted from the observed frequency, the difference is squared and added across all classes to give a measure of the overall difference between observed and predicted values *I.e.:*

$$Overall\ difference = \sum(observed\ frequency\ - expected\ frequency)^2$$

Minimising the difference between observed and calculated frequencies. The program then replaces the parameter values with substitute values, based on their existing values and in steps either entered by the program or provided by the user. It calculates predicted values and then overall differences from observed values for a small cluster of values (the simplex), similar to a point in factor-space. The Nelder-Mead algorithm then uses the difference comparisons between values to replace parameters of the point with the highest difference value with new parameter values likely to reduce the overall difference between calculated and observed values. This process continues, simplex after simplex, until the standard error of the difference function reaches a preset stopping criterion. At this point the overall difference has a minimum value, and the process is said to have converged. The program records the parameter values at that point and the minimum value of the function. One of these 'best' parameter values—the population density—is usually the primary goal of a survey.

A second set of iterations. Provided that the number of iterations has been set higher than 1, the program now carries out its first bootstrapping operation. It samples the original data set at random, with replacement, the same number of times as there are observations in the original data and collates the selected observations into a second frequency distribution. The minimisation process is repeated with this second set of data, producing a second set of 'best' parameter values and another overall function minimum value.

Further sets of iterations. Bootstrapping and function minimisation are once again repeated a number of times until the preset number of iterations has been reached, when the process ends. There is now a pool of parameter estimates for each parameter, one from each set of iterations. The program then proceeds to calculate the sample mean and estimate the standard error of each parameter. A

computed comparison between the observed frequencies and the expected frequencies obtained using these mean values provides a final value of the overall difference at the minimum.

Estimating standard errors of parameter values. Whichever procedure *WildlifeDensity* follows at this point depends on whether or not bootstrapping has been used to produce multiple data sets.

Using multiple data sets from bootstrapping. Provided that the number of iterations has been set greater than 1, each pool of parameter values is used to calculate a standard error, viz. the standard deviation of the sampling distribution of that parameter. Because estimates from bootstrapped data tend to be right-skewed, upper and lower confidence limits are calculated for the density estimate by assuming they follow a log-normal frequency distribution.

Using quadratic surface fitting. If a density estimate alone is needed, and the number of iteration sets is pre-fixed at 1, multiple estimates of each parameter are not computed. Instead, the program follows the procedure in the Appendix to the original Nelder and Mead paper, estimating the standard errors using a quadratic surface fitting procedure derived from Spendley *et al.* (1962). Being based on only a single data set, the standard error estimates tend to be smaller than those computed from the multiple data sets, and are less dependable.

Outputting the results. Whichever strategy has been followed, the program now has an estimate of the population density, the conspicuousness coefficient of the population under the observing conditions, and the associated lateral cover value, together with estimates of their standard errors. The program's output files then inform the user of these values, together with the final modelled frequency distribution and the confidence limits of the density estimate.

A Detectability Approach for Repeated Surveys

The main models above (Equations 5-7) include a component ***g(r).Q(r)*** that incorporates the combined effects of parameters that determine detectability under survey conditions. Parameter values commonly vary in space and time. Sometimes, though, detectability may remain fairly constant over a given time or distance. Followup fieldwork at the site can then be simplified by deriving an expression based on the detectability of a target population under a particular but uniform set of survey conditions. That can be derived from the models already described.

For a set of data collected under an initial set of observing conditions, the effects of all detectability parameters can be combined to give a single function defined as ***the general detectability coefficient (S)*** of the sampling system for a given population under that set of survey conditions. The detectability coefficient *S* is the ratio between the total number of detections *N* made during a line transect or fixed point population survey and the estimated density of the population in the area sampled during the survey. Its derivation for line transects and fixed point surveys is given by **Equation 8** for both types of line transect data and **Equation 9** for fixed observing point data, *viz.:*

$$S = \frac{N}{D\,J\,p_a\,n_s\,L} \qquad [Equation\,8]$$

$$S = \frac{N}{2\,D\,p_s\,p_a\,u\,t} \qquad [Equation\,9]$$

where S = the general detectability function for a given data set ;
N = the total number of individuals detected by observers ;
D = the estimated population density (from Equation 5, 6 or 7) ;
J = the relevant movement correction factor value ;
p_a = proportion of the targeted population observable during a survey and not hidden from view in tree hollows, burrows, nests etc. ($0 < P_a < 1$) ;
n_s = number of transect sides scanned by an observer during a line transect survey (1 or 2, usually 2) ;
L = total transect length ;
p_s = the proportion of a circle surrounding a sampling point scanned by observers during a survey from an observing point ;
u = the mean horizontal displacement rate (m/min) of targeted population members under conditions comparable to those during this survey ; and
t = total time (in min) spent scanning around the observing points.

S is estimated automatically by *WildlifeDensity* using either Equation 8 or 9. Its mean and standard error (in metres) are provided in the program output. Typical S values vary from several hundred in the case of highly conspicuous animals in the open to under 10 for relatively inconspicuous species amongst dense vegetation.

Provided that a followup survey essentially replicates the original conditions, observers no longer need to collect distance measurements or angle data. Once you have an estimate of S, it can provide density estimates for additional sets of field data collected on the same species under similar conditions to those that applied to the data from which S was calculated. Densities can estimated for each transect or sampling point (or combinations of them) using **Equations 10** for line transect data or **Equation 11** for fixed point data, *viz.:*

$$D = \frac{cN}{J\, p_a\, n_s\, L\, S} \qquad [Equation\, 10]$$

$$D = \frac{cN}{2\, p_s\, p_a\;\, u\, t\, S} \qquad [Equation\, 11]$$

where c = a scaling factor (x 10,000 to convert units of D from no./sq m to no./ha; or x 1,000,000 to convert to no./sq km);
N = total number of individuals detected; and

all other variables are as previously defined, but with values for the survey concerned.

If the scaling factor c is left at 1, densities are estimated in number of individuals per square metre. For surveys subsequently repeated in the same census area under similar environmental conditions (e.g. weather, conspicuousness, cover) to those during the initial survey, the detectability coefficient S can be used with Equation 10 or 11 to estimate the population density in the area during the repeat census.

Estimating Detectability at a Transect Line or Observing Point

Field workers may wish to know the proportion of the population at the transect line or observing point (*y=r=0)* detectable under survey conditions. Because the observer's own position is at the transect line or observing point, we can assume that the mean value of that proportion should approximately equal the accumulated probability of both presence and detection across the complete range of horizontal detection distances from the maximum possible distance r_{max} to the minimum possible distance r_{min}. At r_{max} the accumulated probability of detection is 0, if all have been detected by r_{min} it will be 1. However, if there are still undetected animals at the observer's position (where *r*=0), the accumulated probability there will be less than 1. Its value should — on average — approximately equal the proportion of the population *p*(*y*=0) detectable at the transect line or observing point.

Given that the probability of both presence and detection at any distance *r* is given by Equation 4, the overall likelihood of detection p_d within any observing arc of width *Δr* and mean distance r becomes $p_d = Δr.g(r).Q(r_{n-1})$. Because detection begins at the maximum detection distance r_{max} and its likelihood steadily increases thereafter as detection distances become shorter, the estimated proportion detected at any horizontal radial distance *r* will approximately equal the accumulated likelihood of detection from r_{max} to *r.* By the time the observer's location is reached, the overall proportion detected there should approximately equal the sum total of all p_d values from r_{max} to 0. If all have been detected, this should have reached 1; if there are still undetected animals at the observer's position, the sum total $p_{(y=0)}$ will have a value less than 1.

Provided that observing conditions along a transect line or at an observing point are typical of those in the survey area, as a whole, the accumulated probabilities of both presence and detection in all observing arcs from r_{max} to 0 can provide an estimate of the proportion of the population $\mathbf{p_{(y=0)}}$ detectable at the observer. This is given by Equation 12, *viz.:*

$$p_{(y=0)} \approx \sum_{r=0}^{r_{\max}} \Delta r \cdot g(r) \cdot Q(r_{(n-1)}) \qquad [Equation\,12]$$

where	$p_{(y=0)}$	=	population proportion detectable at the observer ;
	r_{max}	=	maximum radial detection distance ;
	r	=	radial detection distance at the observer's position ;
	ΔrΔr.	=	a narrow observing (scanning) arc width ;
	g(r)	=	probability that an observer will detect a targeted animal at a distance r from the observer (from Equation 2) ;
	$Q(r_{(n-1)})$	=	probability of previously undetected presence in the observing arc at distance $r_{(n-1)}$ from the observer (from Equation 3); and
	$r_{(n-1)}$	=	mean distance to the preceding observing arc.

WildlifeDensity calculates an estimate of this proportion and includes it in the *.results* output.

At the theoretical limit, when *Δr* approaches zero, Equation 12 can be expressed in integral form, as:

$$p_{(y=0)} = \int_0^{r_{\max}} g(r)\ Q(r)\ dr$$

Appendix B:

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Wildlife Sampling Methods

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Appendix C:

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