DENSITY FROM DISTANCES

A program for calculating animal and plant
densities using plotless and distance
sampling methods

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I. Introduction

DfD (Density from Distances) is a Windows® program that offers a range of analytical techniques commonly used by ecologists to estimate animal and plant density. Researchers in other fields may also find these methods useful for estimating density. *DfD* has been designed to be easy to use and is particularly suitable for ecological teaching because it allows students to quickly enter or simulate data and explore a range of methods within a familiar Windows setting.

The survey methods used in *Density from Distances* aim to estimate density using observations on the distance between objects or from a selected line or point to the animals or plants and thus do not require the worker to accurately map out or define the sampling area. They are particularly appropriate for the estimation of population density for plants or large animals living at low density in difficult to traverse habitat. For example, distance sampling using a Fourier series is frequently the method of choice for estimating population size of primates in neotropical forest. The animals are counted while walking along specially cut forest trails. The high density of the forest and the low density and mobility of the monkeys would make it futile to try to census a number of pre-defined quadrates. Distance methods are particularly appropriate for static objects such as plants and nests. For bird surveys the difficulty of accurately estimating distance results in the need for simple point or line transect methods where distance is divided into two or more categories. Such methods are available in *DfD*. An important feature of the program is the range of simulations that can be undertaken. These are useful for both students who wish to learn about the various methods and researchers who need to appreciate the level of accuracy they are likely to obtain. The simulated data can be the basis of a classroom practical of the merits of the various methods.

II. Installation and General instructions

A. System requirements
1. A PC running Windows® 95 or later operating system.
2. Minimum of 2 MB spare hard disk space.

B. Installation
1. Place the *DfD* CD in the CD drive.
2. The installation program should start automatically; follow the on-screen instructions.
3. If the CD does not auto-play, browse the CD in Windows Explorer or My Computer, and double-click Setup.exe in the root directory.

When installation is complete there will be a *DfD* entry on your Start: Programs menu and a folder, C:\Program Files\DfD on your hard disk that holds the program files. An uninstall program will also be created to remove the program if you wish. The instruction manual (in Adobe Acrobat PDF format) is also available from the Start: Programs: DfD menu.

C. General instructions
Start *DfD* in the normal Windows fashion either by clicking on the program icon or from the start button. Along the top bar are a number of pull-down menus. These work in the same way as standard Windows programs.

File: To open, initiate, print, export and save data sets.
Edit: The standard Windows menu.
Options: Allows the setting of defaults, window views and units of measurement.
Simulations: To simulate plotless and transect data.
Help: to enter the Help system.
About: Details about the program version.

When the program is started, you will be presented with a blank data grid. From the File menu choose **Open** to load an existing data set and **New** to start entering new data. To enter new data select the type of data you wish to enter from the drop-down menu above the data grid and fill in the grid with appropriate data. To see the type of data that is required run simulations from the **Simulation** drop-down menu and view the data grid.

D.   Obtaining help

For most active windows context sensitive help can be obtained by pressing F1, clicking on the help button or selecting the help drop down menu. Help and frequently asked questions are available on our web site at http://www.pisces-conservation.com

If you have problems using the program or entering data which you cannot solve then contact Pisces Conservation Ltd by e-mail pisces@irchouse.demon.co.uk or by phone to England 44 (0)1590 676622 during office hours (09.00 to 17.00).

E.   Opening a data set

Use **File|Open** to start the file dialogue to select an existing data file for analysis. The default file extension is .csv as the data is stored in simple comma delimited form.

F.   Demonstration data sets

DfD is supplied with a number of demonstration data sets as follows:

Stakes.csv The stakes demonstration data set for a line transect from page 62 of Burnham et al (1980).

p68_belt.csv An example of a line transect with distance belts from page 68 of Burnham et al. (1980).

Multi_point.csv Multiple point data for a simulated data set with an actual density of 0.05 objects per square metre.

Closest.csv A closest neighbour data set from a population with a density of 1 per square metre.

KM.csv A data set of distances from a random point to its closest object and from this object to its nearest neighbour for a population with a density of 1 object per square metre.

G.   Data entry

Data is entered in the *Data* window that is opened by clicking on the *Data* tab. To create a new data set select **File| New** from the pull-down menu. Because the different methods require different data structures you must then select the method you want to apply from the drop down menu in the top panel. The different options and the data they require are described below. The data simulator will automatically organise the data correctly. See **Setting and Changing Units** to select the units used to measure distances.

Transect, Perpendicular Distance

Select this option if you want to estimate density for line transect data and you have a series of measurements of perpendicular distance from the transect line. The data grid that will be formed is shown below. You must also select the units of measurement in the drop-down menu on the right-hand side of the top panel.

To enter data click on a cell and type. To move down a row press the return key or move the mouse to the cell and click. Cells holding perpendicular distances will be coloured blue. To add another transect click on the *Add New Transect* button. All the data for a transect can be removed by double clicking its title cell and selecting *Delete Column*. This dialogue box also allows the transect title to be changed.

Transect, Distance and Angle

Select this option if you want to estimate density for line transect data and you have a series of measurements of the distance to the objects and their angle from the transect line. The data grid that will be formed is shown below. You must also select the units of measurement in the drop-down menu on the right-hand side of the top panel.

To enter data click on a cell and type. To move down a row press the return key or move the mouse to the cell and click. Cells holding perpendicular distances will be coloured blue. To add another transect click on the *Add New Transect* button. All the data for a transect can be removed by double clicking its title cell and selecting *Delete Column*. This dialogue box also allows the transect title to be changed.

Transect, Perpendicular Distance - belted

Select this option if you want to estimate density for line transect data and you have a series of the number of counts of objects in set belts of distance away from the transect line. The data grid that will be formed is shown below. In the outer limit column place the distance to the outer edge of each band. You must also select the units of measurement in the drop-down menu on the right-hand side of the top panel.

To enter data click on a cell and type. To move down a row press the return key or move the mouse to the cell and click. Cells holding perpendicular distances will be coloured blue. To add another transect click on the *Add New Transect* button. All the data for a transect can be removed by double clicking its title cell and selecting *Delete Column*. This dialogue box also allows the transect title to be changed.

Point transect

Select this option if you want to estimate density for point transect data and you have a series of measurements of the distance to the objects. The data grid that will be formed is shown below. You must also select the units of measurement in the drop-down menu on the right-hand side of the top panel.

To enter data click on a cell and type. To move down a row press the return key or move the mouse to the cell and click. Cells holding perpendicular distances will be coloured blue. To add another transect click on the *Add New Transect* button. All the data

for a transect can be removed by double clicking its title cell and selecting *Delete Column*. This dialogue box also allows the transect title to be changed.

Point transect – with belts

Select this option if you want to estimate density for point transect data and you have a series of the number of counts of objects in set belts of distance away from the observation point. The data grid that will be formed is shown below. You must also select the units of measurement in the drop-down menu on the right-hand side of the top panel.

To enter data click on a cell and type. To move down a row press the return key or move the mouse to the cell and click. Cells holding perpendicular distances will be coloured blue. To add another transect click on the *Add New Transect* button. All the data for a transect can be removed by double clicking its title cell and selecting *Delete Column*. This dialogue box also allows the transect title to be changed.

Nearest Neighbour/Closest Individual

Select this option if you want to estimate density using a plotless technique such as nearest neighbour, closest individual or an ordered distance method. The data grid that will be formed is shown below. You must also select the units of measurement in the drop-down menu on the right-hand side of the top panel.

To enter data click on a cell and type. To move down a row press the return key or move the mouse to the cell and click. Cells holding perpendicular distances will be coloured blue. To add another transect click on the *Add New Transect* button. All the data for a transect can be removed by double clicking its title cell and selecting *Delete Column*. This dialogue box also allows the transect title to be changed.

Angle-Order

Select this option if you want to estimate density using the angle-order plotless method. The data grid that will be formed is shown below. You must also select the units of measurement in the drop-down menu on the right-hand side of the top panel.

To enter data, click on a cell and type. To move down a row press the return key or move the mouse to the cell and click. Cells holding perpendicular distances will be coloured blue. To add another transect click on the *Add New Transect* button. All the data for a transect can be removed by double

clicking its title cell and selecting *Delete Column*. This dialogue box also allows the transect title to be changed.

Kendal Moran

Select this option if you want to estimate density using the Kendal-Moran plotless method. The data grid that will be formed is shown below. You must also select the units of measurement in the drop-down menu on the right-hand side of the top panel.

To enter data, click on a cell and type. To move down a row press the return key or move the

mouse to the cell and click. Cells holding perpendicular distances will be coloured blue. To add another transect click on the *Add New Transect* button. All the data for a transect can be removed by double clicking its title cell and selecting *Delete Column*. This dialogue box also allows the transect

title to be changed.

H.   Setting and Changing Units

The units of measurement are selected using the *Select units* drop-down dialogue box in the top panel of the data tab sheet. Units available are millimetres, centimetres, metres, kilometres, feet, yards, miles and nautical miles.

The units of measurement for the calculated density estimates are chosen from **Options|Select density units of measurement**. The units available are square metres, kilometres, nautical miles, miles, yards and feet. You can convert between units at any time even after the density has been calculated.

I.   Editing existing data

The raw data grid can be edited by using the mouse to click on a cell to select it and typing in a new value. These changes will not alter a saved file until **File|Save** is undertaken. Use **File|Save as** to save your data under another name.

J.   Maximum size of the data set

The maximum number of observations in any column is 500.

K.   Printing and exporting your results

Any active window can be printed using **File|Print** and data or graphs can be copied to the clipboard using edit copy in the normal Windows fashion. When print is selected a print preview window is opened in which size, margins, colour etc. can be specified. Copies can be made to the Windows clipboard or to a file from **File|Export** clicking on the **Copy to clipboard** or **Copy to file** buttons in the dialogue box. Images of graphs can be stored as bitmaps, metafiles or enhanced metafiles. For windows users, who wish to include a graph in another document, the metafile or enhanced metafile formats are to be preferred as they will allow the image to be changed in size without loss of resolution of the text.

L.   Zooming and panning on graphs

To zoom in on an area, move to the top left corner of the area to be enlarged then hold the left hand mouse button and drag to the lower right hand corner and release the button. An enlarged view of the selected area will be displayed. To return to the original view, hold down the left-hand mouse button and move upwards and to the left and release. To pan the graph hold down the right hand mouse button and move the mouse.

III.   Line transect methods

Counting the number of sightings forms the basis for estimating density for many animal groups. This is particularly the case for large or easily seen animals such as birds, large grassland mammals, whales and large, active insects such as butterflies. While it may be possible to count animals from a suitable vantage point or while moving along a transect, the count can only be converted to a density estimate if the area scanned can be estimated. This simple approach is often difficult to undertake for two reasons, firstly, it may not be possible to estimate sufficiently accurately the area scanned and secondly, not all of the animals present may have been spotted. Distancing sampling methods have been developed to allow for these problems by assuming that the likelihood that an individual will be observed will decline in a mathematically definable way with distance. The methods available within *DfD* are also useful for sessile or slow moving organisms such as barnacles, corals and molluscs. They can be applied to data collected non-visually if distance can be estimated, for example a bird census may be based on bird song or an electric fish survey on the detection of the distinctive electrical signals. One problem, as can be the case with a visual survey, is to ensure that the same individual is only counted once.

If it is possible to count all of the individuals, n, within a known area, a, then this is termed a census and the estimated density, D, is simply:

$$\hat{D} = \frac{n}{a}$$

Counting often requires the observer to move over the census area and thus favours the use of strip transects (long, thin quadrats) of length, L, and width, 2w, along which the observer moves in a straight line. The counts obtained suffer from error, which varies with the counting rate and bias because of the tendency of observers to undercount. LeResche & Rausch (1974) from a study of bias during aerial surveys of moose *Alces alces* concluded that this bias was sufficient to invalidate the method as a means of absolute population estimation. A survey of 17 studies on large mammals by Caughly (1974) found that the proportion of the population counted varied from 23 to 89%. Dodd & Murphy (1995) made a comparison of census methods for bird nest estimation.

A.   Point and line survey theory

1.   Line transect methods: the Fourier series estimator

Line transect methods have been developed for situations when it is not possible to count all the animals within a strip transect. The methods are based on the idea that only animals lying on the centre line of the of the strip transect along which the observer moves will be certain to be detected and that the probability of detection will fall with perpendicular distance from this line. The techniques presented here have been reviewed in detail by Buckland *et al.* (1993). For many animals the observer may walk the transect, but counts can also be undertaken from motor vehicles, ships and remote operated vehicles.

For these methods it is assumed that:

1. Objects on the line are always detected.

2. The observer does not influence the recorded positions. For mobile animals, the position must be that prior to any response to the presence of the observer: The theory has been developed under the assumption that the objects are immobile, but slow movement in relation to the observer creates little inaccuracy.

3. Distances and/or angles are measured accurately.

4. The objects are correctly identified

Perpendicular distance

Angle

Sighting distance
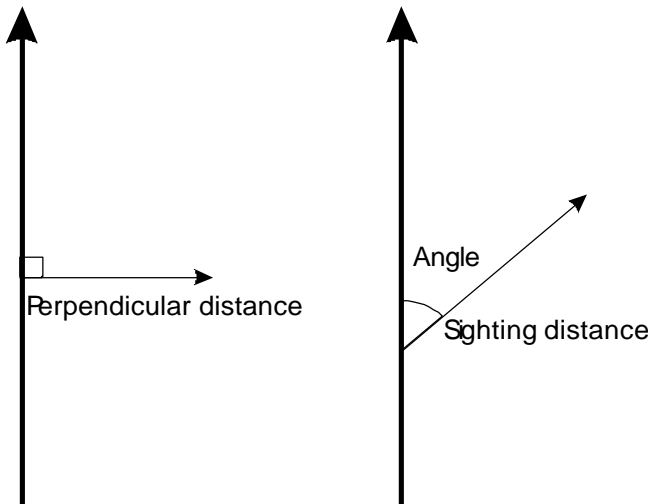
The basic field procedure is for the transect route to be a straight line of length, L, randomly placed with respect to the animals or objects to be counted and the perpendicular distance to each detected object of interest, x, recorded. In practice a number of lines, arranged as a regular grid, and randomly placed in the study may be used. Further, it is usually easier to record the sighting distance, r, which is the distance from the observer to the object, and the sighting angle, θ, which is the angle of the object from the transect line and calculate x rather than measuring x directly. Methods of population estimation based on r and θ were reviewed by Hayes & Buckland (1983) but are not available in *DfD* as they are considered inferior to those based on the perpendicular distance (Buckland *et al.*, 1993).

If all n objects in a strip of length, L, and width, 2w are counted then the estimated density is:

$$\hat{D} = \frac{n}{2wL} \quad .$$

If a proportion, P, of the animals present are detected then the equation becomes:

$$\hat{D} = \frac{n}{2wLP} \quad .$$

Line transect methods use the distribution of the perpendicular detection distances to estimate P.

It is assumed that the number of observations will decline with perpendicular distance from the line and a detection function, g(x) which describes this reduction is fitted to the data. Given assumption (1) above, g(0), the probability of detecting an object lying on the line, is assumed to equal 1.

The probability of detecting an object within a strip of area 2wL, P, is:

$$P = \frac{\int_0^w g(x)\,dx}{w} \quad ,$$

which on substitution gives

$$\hat{D} = \frac{n}{2L\int_0^w \hat{g}(x)\,dx}$$

As it is assumed g(0) =1, the probability density function (pdf) evaluated at x = 0 is

$$f(0) = \frac{1}{\int_0^w g(x)\,dx}$$

and thus the general estimator of density is often expressed as:

$$\hat{D} = \frac{n\,\hat{f}(0)}{2L} \quad .$$

Density is expressed as numbers per square unit of length where length of the transect and distance to the objects are expressed in the same length units such as metres or kilometres. A flexible function with the desired properties to use as a detection function is a cosine series. This is the Fourier model of Crain *et al.* (1979) and is a general model that has been shown to give good results for a wide variety of data.

When perpendicular distance has been measured as a continuous variable and not grouped into size classes the Fourier series f(0) is given by:

$$\hat{f}(0) = \frac{1}{w^*} + \sum_{k=1}^{m} \hat{a}_k \quad ,$$

where

$$\hat{a}_k = \frac{2}{nw^*}\left[\sum_{i=1}^{n} \cos\left(\frac{k\boldsymbol{p}x_i}{w^*}\right)\right]$$

w^* is the transect half-width; without truncation this is the largest perpendicular distance observed; x_i the perpendicular distance of the ith animal, n the number of observations and m the number of cosine terms determined by the stopping rule. that you choose the first value of m such that

$$\frac{1}{w^*}\left(\frac{2}{n+1}\right)^{\frac{1}{2}} \geq \left|\hat{a}_{m+1}\right| \quad .$$

Experience suggests that m should be < 7.

Having calculated *f*(o) D is estimated. The sampling variance of D requires considerable computation. First calculate the variance and covariances of the parameters a_k

$$\mathrm{var}(\hat{a}_k) = \frac{1}{n-1}\left[\frac{1}{w^*}\left(a_{2k} + \frac{2}{w^*}\right) - a_k^2\right] \quad ,$$

$$\text{cov}(\hat{a}_k, \hat{a}_j) = \frac{1}{n-1} \left[\frac{1}{w^*} \left(a_{k+j} + a_{k-j} \right) - a_k a_j \right] \quad .$$

Then sum the variance-covariance matrix to give

$$\text{var}\left(\frac{1}{\hat{a}} \right) = \sum_{j=1}^{m} \sum_{k=1}^{m} \text{cov}\left(\hat{a}_j, \hat{a}_k \right) \quad .$$

Finally, the estimated variance is calculated using

$$\text{var}\left(\hat{D} \right) = \hat{D}^2 \left[\frac{\text{var}(n)}{n} + \frac{\text{var}\left(1/\hat{a} \right)}{\left(1/\hat{a} \right)^2} \right] \quad .$$

It is normally assumed that the variance of the number of animals counted, var(n) is a Poisson variable so that it is equal to n. As this need not be so, Burnham *et al.* (1980) suggest that a sounder approach is to undertake a number of replicate transects, calculate D for each and then find the variance of these replicates.

Buckland *et al.* (1993) argue that extreme observations of perpendicular distance should be removed from the data set prior to calculating population density. As a rough rule, they suggest that 5% of the data should be truncated.

The Fourier series method can also be applied to grouped data. Such data are generated when it is impossible to assign observations to accurately measured distances so they are allocated to distance bands such as 0-5, 5-10,10-15 and 15-20 metres. It may also be advantageous to group data when bias in favour of certain distances is suspected. A description of these methods is beyond the scope of the present text. If possible grouping data should be avoided as it reduces accuracy (Southwell & Weaver, 1993).

From the above Fourier model it can be seen that the key computational issue is the estimation of g(x) or f(0).

2.   Point transects

Instead of traversing a transect the observer may move to a number of fixed points and record the distance, r, to individual animals. These methods are almost only used for bird surveys where the patchy suitability of the habitat to the birds may make line transects inappropriate because they cut across a number of habitat types. Point transects are often easier to undertake because the observer needs only estimate distance and markers may be placed in advance to aid the estimation of distance. Population density is given by:

$$\hat{D} = \frac{n \hat{h}(0)}{2 p k}$$

Where n is the number of animals observed, k the number of point transects undertaken and h(0) the slope of the probability density function of detection distances evaluated at zero distance. In similar fashion to what was described for the line transect method the central problem is to estimate h(0).

For the case of a half normal detection function the maximum likelihood estimator for density has the particularly simple form:

$$\hat{D} = \frac{n^2}{2 p k \sum_{i=1}^{n} r_i^2} \quad .$$

## B.   *Fourier model for full distance line transect data*

To apply this method you will require data of either the perpendicular distances from the transect line to the objects or the distance to the objects plus their angle from the line.

If you have perpendicular distances for each transect then select *Transect, Perpendicular Distance* from the drop down menu on the data form. If you wish to enter distance and angle select *Transect, Distance, angle*. All the calculations are undertaken using the perpendicular distance which is calculated by *DfD* when distance/angle data is supplied. The distance observations for each transect are entered in columns and additional transects are added using the *Add New Transect* button on the data form. The length of each transect must be entered at the head of the first column for each transect and the units of measurement selected from the drop-down menu. The units of measurement for both the distances to objects and the length of the transects must be in the same.

To obtain a density estimate either click on the *F* button at the top of the window or click on the Select Model tab and click on the *Fourier model* button

1.   **Viewing the histogram of distances**

Select the Histogram tab to view the distribution of distances observed. When multiple transects have been entered into the data grid the transect to display is selected from the *Plot transect* drop-down menu. The number of bins (frequency classes) for the distance data is selected using the *Select bin number* drop-down. If a line transect model has been run then the detection function with be plotted on the graph as a green line.
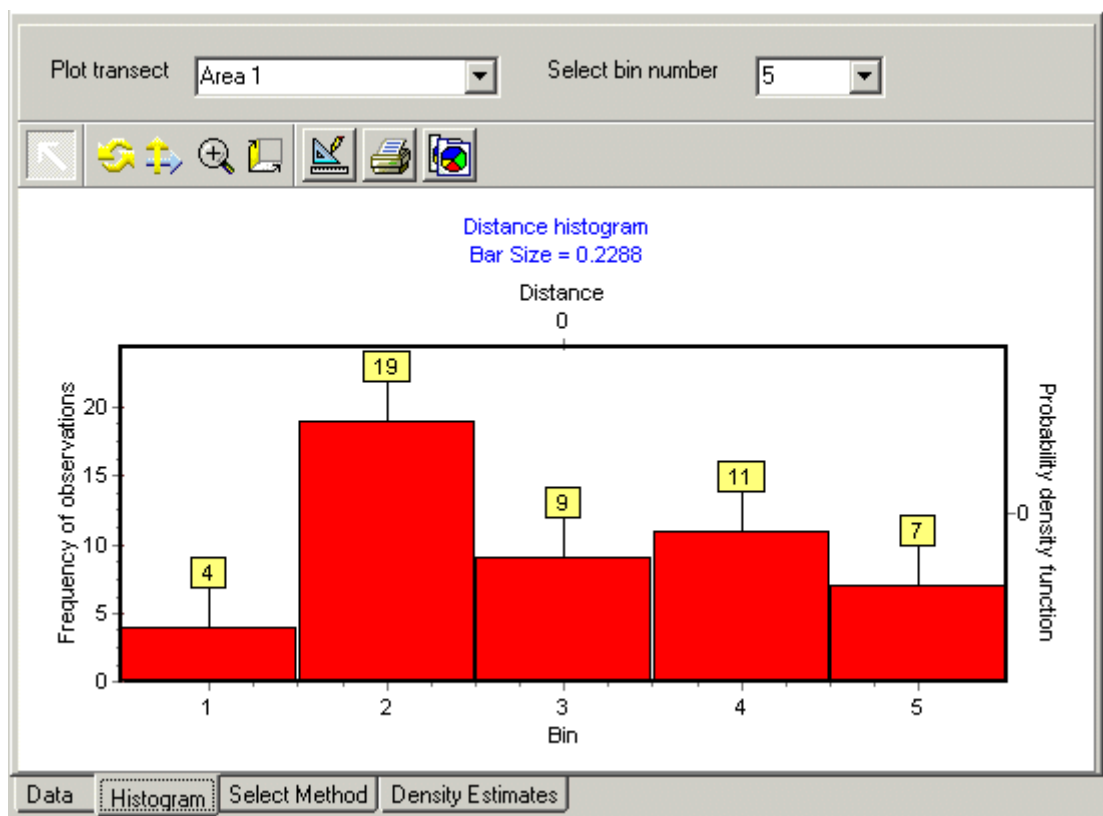
2.   **Truncating the data**

It is generally advisable to truncate distance data to remove some of the largest distances observed. Click on the truncation tab to view the histogram selected in the Histogram tab. The percentage of observations to remove is then selected using the radio buttons at the top of the graph. To select a particular cut level select *Custom* and use the edit box to select the

percentage required. The observations that will be omitted from the calculation are shown in green.
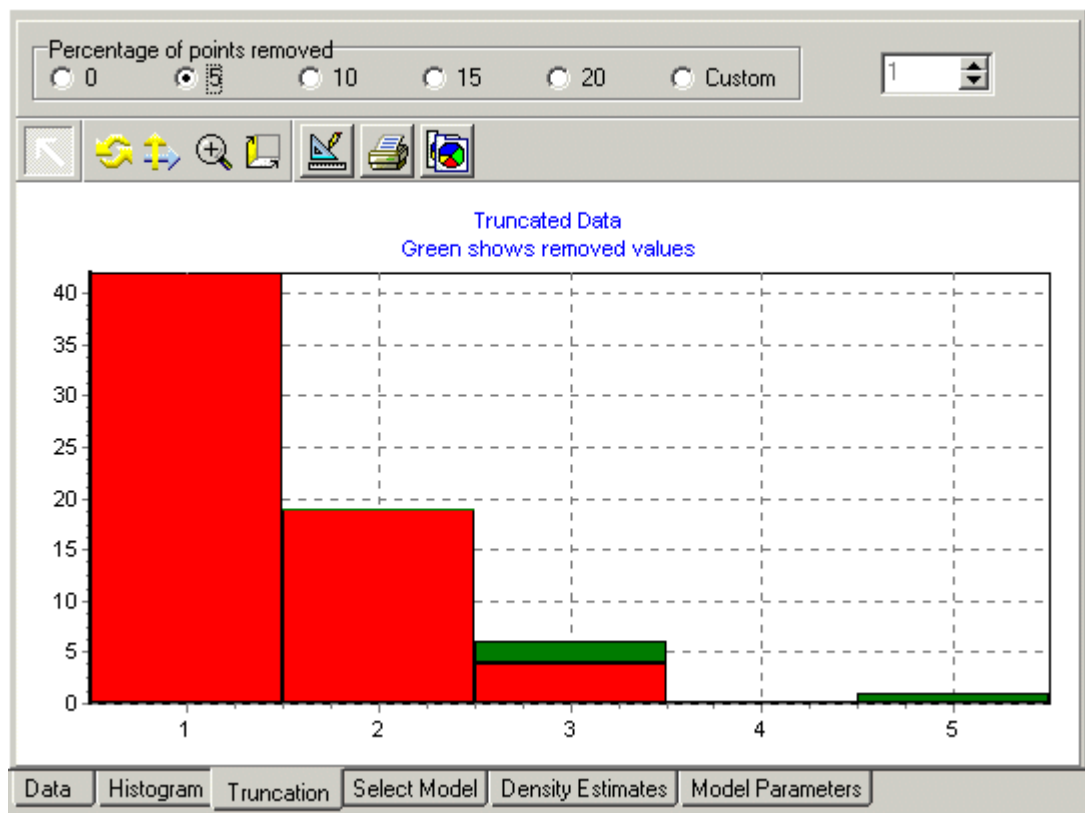
Once a cut level has been applied this will be used for future calculations when a model is selected. Truncation is not applied to the half normal point transect model.

3.   Viewing the results

Once an analysis has been undertaken the density estimates for each transect are viewed using the *Density Estimates* tab. The results for each transect are arranged in a grid. In addition to the density the grid gives the variance and the standard error of the estimates and gives the average density for all the transects. See **Setting and Changing Units** above to change the units of measurement.

Transect id	Density	Units	Variance	Standard error	Average
1	1.414E6	/sq. nautical miles	6.622E21	8.136E10	
					1.414E6

The parameters calculated for the Fourier model are viewed using the *Model Parameters* tab. The parameters for each transect are presented on separate rows. Column 2 gives the estimate for f(0) which is used to calculate the estimated density. In the next column is given the number of terms of the Fourier series that were used for the calculation. DfD determines automatically using a standard stopping rule the appropriate number of terms. The first six terms for the Fourier series are given in columns 4 to 9. If only 2 terms were used for the calculation then only a(0) and a(1) would be used to form the detection function.

Transect id	f(0)	Terms used	a1	a2	a3	a4	a5	a6
1	0.1728	1	0.0674	-0.003826	0.01478	0.005161	-0.001784	0.0004723

A plot of the detection function used for the calculation can be viewed by selecting the Histogram tab.

C.   Half-normal model for full distance line transect data

To apply this method you will require data of either the perpendicular distances from the transect line to the objects or the distance to the objects plus their angle from the line.

If you have perpendicular distances for each transect then select *Transect, Perpendicular Distance* from the drop down menu on the data form. If you wish to enter distance and angle select *Transect, Distance, angle*. All the calculations are undertaken using the perpendicular distance which is calculated by DfD when distance/angle data is supplied. The distance observations for each transect are entered in columns and additional transects are added using the *Add New Transect* button on the data form. The length of each transect must be entered at the head of the first column for each transect and the units of measurement selected from the drop-down menu. The units of measurement for both the distances to objects and the length of the transects must be in the same.

To obtain a density estimate either click on the *N* button at the top of the window or click on the Select Model tab and click on the *Half normal* button

1.   Viewing the histogram of distances

See Section B.

2.   Truncating the data

See Section B.

3.   Viewing the results

Once an analysis has been undertaken the density estimates for each transect are viewed using the *Density Estimates* tab. The results for each transect are arranged in a grid. In addition to the density the grid gives the variance and the standard error of the estimates and gives the average density for all the transects.

The parameters calculated for the model are viewed using the *Model Parameters* tab.

A plot of the detection function used for the calculation can be viewed by selecting the Histogram tab.

D.   All objects detected during line transect surveys

This option is included so that you can see what the density estimate would be if all the objects were detected. The program assumes that the counts are for a strip transect with a width equal to twice the maximum perpendicular distance observed. If truncation is applied then the maximum distance for the truncated data set is used.

To obtain a density estimate either click on the *All* button at the top of the window or click on the Select Model tab and click on the *All objects detected* button.

Once an analysis has been undertaken the density estimates for each transect are viewed using the *Density Estimates* tab. The results for each transect are arranged in a grid. In

addition to the density the grid gives the variance and the standard error of the estimates and gives the average density for all the transects.

E.   Fourier model for n-belt line transect data

To apply this method you will require data of the number of objects counted in defined belts away from the transect line. The observations for each transect are entered in pairs of columns. In the first column is entered the outer limit of each belt and in the second the number of objects observed within this belt. The length of each transect must be entered at the head of the first column for each transect and the units of measurement selected from the drop-down menu. The units of measurement for both the distances to objects and the length of the transects must be in the same.

To obtain a density estimate either click on the *F* button at the top of the window or click on the Select Model tab and click on the *Fourier model* button

1.   Viewing the histogram of distances

See Section B.

2.   Viewing the results

Once an analysis has been undertaken the density estimates for each transect are viewed using the *Density Estimates* tab. The results for each transect are arranged in a grid. In addition to the density the grid gives the variance and the standard error of the estimates and gives the average density for all the transects.

The parameters calculated for the Fourier model are viewed using the *Model Parameters* tab. The parameters for each transect are presented on separate rows. Column 2 gives the estimate for f(0) which is used to calculate the estimated density. In the next column is given the number of terms of the Fourier series that were used for the calculation. DfD determines automatically using a standard stopping rule the appropriate number of terms. The first six terms for the Fourier series are given in columns 4 to 9. If only 2 terms were used for the calculation then only a(0) and a(1) would be used to form the detection function.

A plot of the detection function used for the calculation can be viewed by selecting the Histogram tab.

3.   Goodness of fit

The goodness of fit tab shows the observed and expected frequencies in each belt and a chi-squared test for the goodness of fit. The expected values are calculated using the calculated Fourier parameters.

F.   Linear detection model for 2-belt line transect data

Simple two belt models are often used for animals such as birds where it is difficult to measure distance accurately. The counts simply comprise the numbers observed within and beyond a set distance from the transect line.

The density of the objects is calculated as

$$D = 10N^{\left(1 - \sqrt{1 - N_1/N}\right)} \Big/ wL$$

where w is the distance to the outer edge of the inner belt in metres, N the total objects observed, N_1 the number of objects within the inner belt and L the length of the transect in kilometres.

1.   Viewing the results

Once an analysis has been undertaken, the density estimates for each transect are viewed using the *Density Estimates* tab. The results for each transect are arranged in a grid. In addition to the density the grid gives the variance and the standard error of the estimates and gives the average density for all the transects.

G.   Exponential detection model for 2-belt line transect data

Simple two belt models are often used for animals such as birds where it is difficult to measure distance accurately. The counts simply comprise the numbers observed within and beyond a set distance from the transect line. The density of the objects is calculated as

$$D = 5N \frac{\left(-\ln\left(1 - \frac{N_1}{N}\right)\right)}{wL}$$

where w is the distance to the outer edge of the inner belt in metres, N the total objects observed, N_1 the number of objects within the inner belt and L the length of the transect in kilometres.

1.   Viewing the results

Once an analysis has been undertaken, the density estimates for each transect are viewed using the *Density Estimates* tab. The results for each transect are arranged in a grid. In addition to the density the grid gives the variance and the standard error of the estimates and gives the average density for all the transects.

H.   Point transect - 2-belt model

Point transects are most frequently used for bird surveys where it is usually impossible to accurately record the distance to each sighting and line transect methods are inappropriate because the birds are localised into particular parts of the habitat. Given these limitations a simple two belt method is appropriate. The density of the objects is calculated as

$$D = \ln\left(\frac{N}{N_2}\right)\frac{N}{pr^2}$$

where N is the total number of objects counted and N_2 the number beyond the fixed radius r.

1.   Viewing the results

Once an analysis has been undertaken, the density estimates for each transect are viewed using the *Density Estimates* tab. The results for each transect are arranged in a grid. In addition to the density the grid gives the variance and the standard error of the estimates and gives the average density for all the transects.

I.   Point transect - half normal model

This method can be used when point transects have been used to measure the distances to each object detected. The detection function is modelled as a half normal function and the density is estimated using:

$$D = \frac{n^2}{p\sum_{i=1}^{n} d_i^2}$$

where n is the number of objects observed and d_i the distance to the ith object.

1. Viewing the results

Once an analysis has been undertaken, the density estimates for each transect are viewed using the *Density Estimates* tab. The results for each transect are arranged in a grid. In addition to the density the grid gives the variance and the standard error of the estimates and gives the average density for all the transects.

IV. Plotless density estimators

These methods are used to estimate the density of stationary objects in the field. Although most obviously applicable to plants they can also be used for many static or slow moving animals or their signs such as ant hills and nests. They are especially useful in situations where the use of quadrate sampling would be difficult or too costly. However, while the accuracy of the density estimate obtained by quadrate sampling is relatively insensitive to the spatial distribution of the object under study this is not the case with plotless methods. Unfortunately, there is no clearly superior plotless density estimator as the methods differ in their ability to handle different types of spatial distribution. In practice, it is important to select the method that offers the easiest and quickest field measurements commensurate with the accuracy required. To help you with this task *DfD* offers a data simulation facility. Methods that are more robust could be developed, but they would be too costly to use. Engeman *et al* 1994 reviewed the quality of the density estimates obtained using the various estimators available and *DfD* implements all of the less costly methods that they found best. However, their study used simulated data and the situation in the field can be even more adverse than even they assumed. There can be no substitute for a pilot study in which a known density of the objects of interest is estimated by a variety of plotless estimates to determine the most cost-effective method.

The following points should be considered when considering a survey using plotless methods.

1. You must have some idea of the effort required to collect measurements in the field.

2. You should have some idea of the spatial distribution of the objects under study - can they be assumed to be random, regularly distributed, clumped or highly clumped?

3. If the distribution is clumped (as is often the case) then the best methods offered by *DfD* are Angle-order-second nearest-individual, ordered-distance-third nearest individual and the Kendall-Moran estimators.

4. The Angle-order estimators are more costly than the other methods to implement so it is wise to use simulations to decide if ordered-distance or Kendal-Moran estimators might be acceptable. Engeman *et al* 1994 suggest that angle-order methods are unlikely to reward the user for their increased cost by producing greatly superior estimates.

5. Generally, it seems better to use more sampling points rather than investing a large effort at a small number of points. This is because the spatial pattern of the study objects can change over the sampling area. It is therefore often essential to place sufficient sampling points to give good coverage.

6. If you can assume that the objects are randomly distributed then you can use either closest-individual or nearest-neighbour estimators which are the simplest and least costly of methods to use. If these "basic distance" methods are to be applied tests of randomness must be carried out. For populations sampled in quadrates, with a mean greater than one, the Poisson Index of Dispersion is a satisfactory test of randomness. Seber (1982) gives other test procedures.

A. Closest individual (Cottam et al., 1953)

To use this estimator you will require a series of measurements of the distance from a randomly selected point to the closest individual. For each study area, the distances are entered as a single column.

Density, D, is calculated using:

$$D = \frac{1}{\left(4\left[\frac{R_i}{N}\right]^2\right)}$$

where R_i is the distance from the ith random point to its closest individual and N the number of random sampling points.

DfD can simulate data collected using this method so that you can appreciate the likely errors.

B.   Nearest neighbour (Cottam & Curtis, 1956)

To use this estimator you will require a series of measurements of the distance from a randomly selected individual to its closest neighbour. The problem is that it is not really possible to randomly select the individuals to measure from in the field. For each study area, the distances are entered as a single column.

$$D = \frac{1}{\left(4\left[\frac{H_i}{N}\right]^2\right)}$$

Density, D, is calculated using:

where H_i is the distance from the ith individual to its closest neighbour and N the number of measurements made.

DfD can simulate data collected using this method so that you can appreciate the likely errors.

C.   Kendall-Moran (Kendall and Moran, 1963)

For this method you will require a series of pairs of measurements of the distance from a randomly selected point to the closest individual and from this individual to its nearest neighbour. For each study area, the distances are entered as over two columns. The first column holds the distance to the closest individual and the second column the distance to its nearest neighbour. The program calculates the area searched which is the sum of the circular areas within the radii of the closest individual and its nearest neighbour minus the overlap.

Density, D, is calculated using:

$$D = \frac{P + N - 1}{\sum B_i}$$

where P is the number of closest individuals, N the number of nearest neighbours and B_i the combined search area from the ith sampling point for the closest individual and its nearest neighbour.

DfD can simulate data collected using this method so that you can appreciate the likely errors.

D.   Ordered distance closest individual (Morista, 1957)

To use this estimator you will require a series of measurements of the distance from a randomly selected point to the closest individual. For each study area, the distances are entered as a single column.

Density,D, is calculated using:

$$D = \frac{(N-1)}{p \sum (R_i)^2}$$

where R_i is the distance from the ith random point to its closest individual and N the number of random sample point.

Seber (1982) as gives the variance of D:

$$\text{var}[\hat{D}] = \frac{\hat{D}^2}{(N-2)} \quad .$$

DfD can simulate data collected using this method so that you can appreciate the likely errors.

E.   Ordered distance second closest individual (Morista, 1957)

To use this estimator you will require a series of measurements of the distance from a randomly selected point to the second closest individual. For each study area, the distances are entered as a single column.

Density, D, is calculated using:

$$D = \frac{(2N-1)}{p \sum (R_i)^2}$$

where R_I is the distance from the ith random point to its closest individual and N the number of random sample point. Seber (1982) as gives the variance of D as:

$$\text{var}[\hat{D}] = \frac{\hat{D}^2}{(2N-2)} \quad .$$

DfD can simulate data collected using this method so that you can appreciate the likely errors.

F.   Ordered distance third closest individual (Morista, 1957)

To use this estimator you will require a series of measurements of the distance from a randomly selected point to the third closest individual. For each study area, the distances are entered as a single column. Density, D, is calculated using:

$$D = \frac{(3N-1)}{p \sum (R_i)^2}$$

where R_i is the distance from the ith random point to its closest individual and N the number of random sample point.

Seber (1982) as gives the variance of D as:

$$\text{var}[\hat{D}] = \hat{D}^2 \Big/ (3N-2)$$

.

DfD can simulate data collected using this method so that you can appreciate the likely errors.

G. Angle-order nearest individual (Stearns, 1949)

This is a 'point-centred-quarter' method. For each randomly selected point the area around it is divided into equal quarters and the distance to the nearest individual in each quarter recorded. Density, D, is calculated using:

$$D = 12 \Big/ p \sum 1/R_{ij}^2$$

where R_{ij} is the distance from the ith random point to its closest individual in the jth quarter and N the number of random sample points.

DfD can simulate data collected using this method so that you can appreciate the likely errors.

H. Angle-order second nearest individual (Morista, 1957)

This is a 'point-centred-quarter' method. For each randomly selected point the area around it is divided into equal quarters and the distance to the nearest individual in each quarter recorded. Density, D, is calculated using:

$$D = 28N \Big/ p \sum 1/R_{ij}^2$$

where R_{ij} is the distance from the ith random point to the second closest individual in the jth quarter and N the number of random sample points.

DfD can simulate data collected using this method so that you can appreciate the likely errors.

I. Data Simulation

Select *Simulation* and either *Transect Data* or *Plotless Density Estimate* from the top menu to simulate transect sampling observations or plotless density estimation protocols. In both cases, following selection, a dialogue window opens in which simulation parameters are selected. These simulators can be used to explore the efficiency of the different methods under a variety of assumptions. Simulated data will be added to data grid and can be viewed and saved in the normal fashion.

1. Plotless density estimation

The dialogue for this simulator is shown below. Within the *Method* panel on the right-hand side select the type of data that you wish to simulate.

The distribution of the objects that will be sampled is selected within the *Distribution Type* panel. This is useful as methods differ in their ability to handle non-random data. Select *Random* to position the objects at random with the study area. This is simulated by using a random number generator to give x and y coordinates. Select *Regular* to arrange the objects in a regular grid pattern and *Clumped* to produce a contiguous distribution. If *Regular* is selected then it is possible to select the degree of regularity by the numerical value placed in the *Noise* edit box. A value of 0 (zero) will be perfectly regular: as the value increases a potentially larger random displacement from the regular distribution is applied to each object. If clumped is selected the *Number of Clumps* can be altered to give the number of clusters of objects within the sample area. The objects are randomly placed within each cluster and the *Tightness* parameter can take any value from 0. The smaller the value the tighter the clusters. Values for tightness above 1 will produce ever more random-like distributions.

Place in the *Density* edit box the required density of the objects in the study area. The default value of 1 is good starting point as it produces a reasonable number of objects.

The value entered into the *Number of Samples* edit box gives the number of samples that will be simulated. For example, if closest individual is selected this will select the number of distances measured from random points to their nearest object.

The length and width of the sampling area is chosen using the *Dimension* edit box. For most studies a 10 by 10 area, which is the default, will be found suitable.

If *Random Seed* is set to 0 (zero) the program selects the random number seed using the date/time function of the computer. Thus, every simulation will be different. To be able to generate exactly the same simulation a number of times enter a number in *Random Seed* and remember it!

Once the simulation parameters have been entered select *Ok* to generate the simulated data or *Cancel* to leave without data generation.

The distribution of the objects and the results of the simulation are shown graphically (next page).
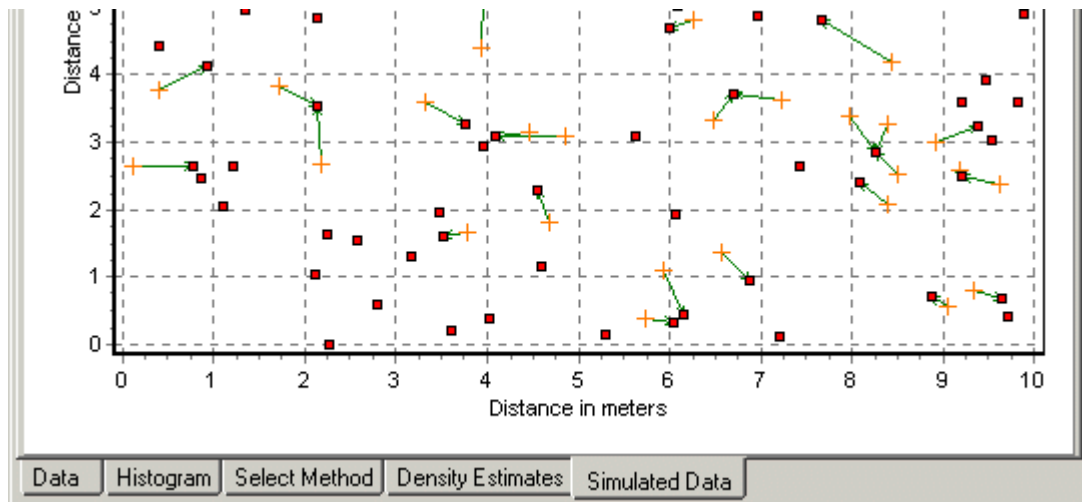
The individual objects are shown as red squares, the selected point or individual as a yellow cross and the distance calculated by the program as a green line.

2. Line transect simulation

The dialogue for this simulator for both point and line transect data is shown below. Within the *Method* panel on the left-hand side select the type of data that you wish to simulate.

The detection function (the decline in the likelihood of an object being spotted with distance) is selected from the Detection Function panel. Depending on the function chosen other parameters may have to be entered in the parameter list on the right-hand side.

Actual density is the density of the objects in the simulated study area. Any real, positive, number can be chosen. However, large numbers may result in an error if the number of objects detected becomes too large. The density is assumed to be measured in objects per square metre.

Transect length is the length of the line transect in metres. Any positive integer can be used although large numbers may result in an overload error if the number of objects detected becomes too large.

Maximum detection distance is the maximum distance at which an object will be detected in metres. It is used by the simulator to fix the scale of the sighting experiment you are envisaging.

Inner belt distance is the distance to the outside limit of the inner belt in metres. This parameter is required when simulating a 2-belt line or point transect.

Std. dev. of detection function is the standard deviation used for a half-normal detection function. The larger the value the more objects will be detected at extreme distances. This should be a real, positive value.

Decay constant is the negative exponential detection function parameter. It is a real, positive number. The larger the value the more rapidly the probability of detection declines with distance.

For both point and line transects the results of the simulations are shown graphically. For line transects the detected objects are shown as red squares and the perpendicular distance as green lines. Undetected objects are shown as blue squares. For point transects detected objects and the sighting distance is shown in red or green and undetected objects in blue. For two belt surveys the colour of the detected object and the sighting line is green if the point is within the inner belt and red if it is the outer belt.

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