Bats: trapping at roosts—estimating population size

Version 1.0

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Contents

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Synopsis

Mark-recapture techniques can be used to estimate population size when a complete count is not possible and when less expensive indices of relative abundance or density cannot be calculated. Mark-recapture studies are dependent on being able to apply recognisable marks to bats that last for the duration of the study. Bats are trapped and marked at roost sites using harp traps (to obtain a large enough sample of animals). Anyone wishing to catch and handle bats must hold appropriate permits, have animal ethics approval and should be familiar with the potential health and safety issues associated with handling bats. Trapping and handling must follow approved best practice procedures that do not disturb the bats unduly (see the 'DOC best practice manual of conservation techniques for bats'—docdm-131465). Bats must be marked using tags or marks that are ethically acceptable and humane. Two types of marks are used:

1. Permanent marks using individually numbered tags (forearm bands for long-tailed bats and Passive Integrated Transponder tags (PIT tags or microchips) for lesser short-tailed bats).
2. Temporary marks for lesser short-tailed bats (fur clips) in lieu of permanent marks.

Note that bands cause injury to lesser short-tailed bats so must not be used, and transponders have now been used successfully.

Bats are recaptured once or several times after a short interval, and mark-recapture analyses are used to estimate population size. A variety of statistical methods ('models') are available for estimating population size. Choice of method depends on the following:

- Whether temporary or permanent marks can be used
- Whether individually recognisable marks can be applied
- Whether the population is 'open' or 'closed' during the sampling period
- Study objectives
- The number of resources and time available for the study

Four approaches to estimating population size are possible. They vary in their precision:

1. Calculating very simple estimates (minimum number of marked bats alive (MNA) following a recapture session).
2. Deriving population estimates from short-term sampling of closed populations (i.e. where there is no birth, death, immigration or emigration during the study) and obtaining an estimate of absolute abundance.
3. Using the recapture probabilities calculated in open-population models to estimate population size.
4. Using robust design models that combine elements of both open- and closed-population modelling.

Closed-population methods (No. 2 above) are recommended if a single estimate of abundance is required, whereas robust design models provide more precise abundance estimates from multiple estimates of abundance. Seek advice of a statistician with expertise in modelling populations before undertaking mark-recapture studies to ensure the correct approach is used, because all approaches have set assumptions that should be met. There are strengths and weaknesses in each approach, and violating the assumptions has different consequences for each approach. These, in turn, may influence the precision of population estimates and hence the conclusions drawn from analyses. Obtaining sufficient samples (i.e. enough individual bats are marked) is virtually impossible if catching bats on their foraging grounds, which is why we recommend harp-trap captures at roost sites as the basis for mark-recapture studies. Marking and recapture methods provide reasonably robust population estimates for long-tailed bats for both inventory and monitoring if (a) individually numbered forearm bands are used to mark animals, (b) sample sizes are large (hundreds of bats), and (c) recapture sessions are undertaken periodically for long enough (> 5 years).

At the time of writing, only simple population estimates have been derived for lesser short-tailed bats because, until recently, temporary marking was the only method approved for this species. However, lesser short-tailed bats have now been tagged successfully using transponders inserted under the skin. Automatic tag readers and data loggers positioned at the roost hole have successfully recorded the number of bats with tags exiting the roost. If this information (number of bats with tags emerging at dusk) is used in conjunction with a simultaneous video count at the same roost (total number of bats emerging), a coarse, one-off population estimate can be calculated (e.g. by using the Lincoln-Petersen Estimator). Population estimation using robust design models for 'open' populations might also become a feasible alternative.

Assumptions

All mark-recapture models have assumptions that must be satisfied to avoid biased estimates. Lettink & Armstrong (2003) summarise all the assumptions for the main methods of estimating population size.

There are a number of general assumptions applicable to all marking methods:

- Marked bats are representative of the population being studied.
- Marks do not influence behaviour or survival of marked animals.
- Loss of contact of a marked animal is random and independent of death.

Assumptions of closed-population models

If there is one marking session and one recapture session, and the population is closed (i.e. no birth, death, immigration or emigration occur during the study), then methods known variously as the Petersen Estimator or Lincoln Index are applicable. This Lincoln-Petersen Estimator assumes that:

- The population is geographically and demographically closed (i.e. the population is constant in size and composition during the study period).
- All animals have the same probability of being caught.
- Marks are not lost.

If there are multiple recapture sessions, and the population is still closed (often referred to as Schnabel methods), then the second assumption (above) does not apply to the analysis.

Assumptions of open-population models

Open-population models (where populations are subject to birth, death, immigration and emigration during a study) are usually used for rigorous analysis of survival in animals. However, if recapture probabilities are high and the assumptions of the model are met, then the recapture probabilities calculated from these models can be inserted in the equations for estimating population size. The Cormack-Jolly-Seber model is the most commonly used and has the following main assumptions:

- Every animal (of the same type) has the same probability of recapture ('equal catchability' or 'capture heterogeneity').
- Every animal (of the same type) has the same probability of survival from one sample to the next.
- Marks are not lost or missed.
- All samples are instantaneous and each release is made immediately after the sample.

Advantages

- The methods obtain results relatively quickly, making them suitable for answering short-term management questions, such as:
  - How large is the bat population at site *x*?
  - Is population size different after a management operation?
  - What proportion of bats survived a management operation?
- The methods can be used to obtain population estimates without having to individually mark all animals in a population.
- If permanent, individual marks can be applied, then more precise population estimates can be calculated.

Disadvantages

- Trapping and mark-recapture methods are dependent on being able to locate roost sites when necessary and catching and marking sufficient numbers of bats quickly and humanely. Times when non-flying young are in a colony should be avoided.
- Large sample sizes are needed to ensure recapture probabilities are high, but it is sometimes hard to catch a lot of bats in a reasonable number of capture sessions. Obtaining sufficient samples is virtually impossible if catching bats on their foraging grounds, which is why we recommend basing this method on captures at roost sites.
- Bats are disturbed by catching, handling and applying marks, and currently, they have to be recaptured subsequently. Thus, caution and care are needed when catching animals.

Guidelines on best practice must be strictly adhered to. In the future, automatic transponder readers set up at roost sites may remove the need to recapture individual short-tailed bats.

- The methods require a large number of skilled workers to handle bats quickly and efficiently.
- If temporary marks are used, or if marks are not specific to individuals, then population estimates will not be very accurate, and, potentially, might only detect gross changes in population over time.
- Estimates are poor for populations that are very mobile because the assumptions of populations being 'closed' are difficult to meet.
- If the assumption of equal catchability of individuals is violated, this will result in a biased population estimate that probably under- or over-estimates population size. This assumption is difficult to meet and violations can be divided into heterogeneity (differences between individuals) and behavioural causes. Animals can be divided into categories such as sex and age, assuming equal catchability in each category, but a larger sample size is required if this approach is used.

Suitability for inventory

Marking and recapture methods provide relatively robust one-off population estimates for long-tailed bats if (a) a large enough sample is marked using individually numbered forearm bands, and (b) the sample of recaptured bats is also large. We do not recommend temporary marking and recapture for long-tailed bats to estimate population size because it is more effective to mark the bats permanently.

Techniques for estimating population size in lesser short-tailed bats are less robust because, although it is now possible to use transponders with this species (Sedgeley & O'Donnell 2006, 2007), their application is not yet routine. Simple population estimates can be derived by using fur-clipping as a temporary mark and then, for example, using the Lincoln-Petersen Estimator. Population estimates derived from recapturing bats with transponder tags will provide more precise estimates of population size in the future.

Suitability for monitoring

These methods are equally suitable for monitoring in both species if the constraints listed above are recognised, and repeat capture and recapture sessions are standardised. Once automatic transponder readers have been fully developed, it may be possible to monitor populations of lesser short-tailed bats more robustly.

Skills

Workers require skills to locate occupied roosts if roost locations are not already known. They also need certain skills to apply the inventory or monitoring method at the roost:

Skills required for finding roosts

Workers must be able to:

- Demonstrate a basic level of bushcraft.
- Identify areas of bat activity by using bat detectors to survey for bat calls. See ‘Bats: counting away from roosts—bat detectors on line transects’ (docdm-590701) and ‘Bats: counting away from roosts—automatic bat detectors’ (docdm-590733) for more information.
- Set up harp traps or construct mist net rigs in areas of bat activity. Training may be needed to learn how and where to place traps to optimise capture rates.
- Handle bats competently and humanely; identify, age, sex and measure them; and apply transmitters.
- Meet minimum standards—anyone wishing to catch and handle bats must receive appropriate training and must meet the minimum requirements for catching, handling, examining, measuring, and releasing bats described in the ‘DOC best practice manual of conservation techniques for bats’ (docdm-131465).
- Use radio-tracking to follow tagged bats and locate their communal roosts (see ‘Bats: trapping at roosts—estimating survival and productivity’—docdm-590867).

Skills required for using mark-recapture at roosts

Workers must be able to:

- Set up harp traps at tree roosts or caves using appropriate catching methods. Training may be needed to learn how and where to place traps to optimise capture rates.
- Handle bats competently and humanely; identify, age, sex and measure them; and apply temporary and/or permanent marks (bands and transponders).
- Meet minimum standards—anyone wishing to catch and handle bats must receive appropriate training and meet the minimum requirements described in the ‘DOC best practice manual of conservation techniques for bats’ (docdm-131465). At the time of writing, the DOC Animal Ethics Committee had only approved two people for injecting transponders into lesser short-tailed bats.
- Apply statistical experience, and have experience with using computers and running computer programs.
- Identify violations of assumptions and the consequences of these on precision of the results.
- Get advice from a specialist statistician.

Resources

Trapping and mark recapture methods are very expensive in terms of equipment and time:

- Intensive effort is required to locate the roosts. Preliminary surveys using bat detectors may be needed to find locations where bats are present.

- Radio-tracking bats is resource intensive, requiring mist nets and/or harp traps for catching bats, ropes to rig nets, transmitters, glue, scissors, antennae, receivers and a vehicle. Radio transmitters (c. $200/tag) and radio-tracking equipment (radio receivers and antennae, c. $3000/unit) are required. Personnel costs can be high when monitoring daily survival of radio-tagged bats as the minimum survey period is 2 weeks (and most surveys go for longer).
- Trapping bats also requires considerable resources in terms of equipment and time required to set up and run the traps. Equipment includes traps, ropes and strings, line-shooting and tree-climbing equipment, infrared video equipment, good spotlights and spare batteries.
- Equipment for marking and processing bats varies depending on the marking method. Holding bags, callipers, Pesola balances, fur-trimmers, clipboards, recording sheets and headlamps are relatively inexpensive. Long-tailed bat bands are also inexpensive, but transponders are more expensive (c. $10 each; injector gun c. $250; transponder reader > $250).
- Although automatic transponder readers are not particularly expensive, units will be required for perhaps 10–20 roost trees and personnel costs will be high, particularly if trees need to be climbed to put the readers in place and then to maintain them (e.g. antenna tunings need to be checked regularly).
- You need a reasonably large pool of skilled workers to handle and mark bats, especially if large samples are sought for use in calculating tagging ratios.

Minimum attributes

Consistent measurement and recording of these attributes is critical for the implementation of the method. Other attributes may be optional depending on your objective. For more information refer to ‘Full details of technique and best practice’.

DOC staff must complete a ‘Standard inventory and monitoring project plan’ (docdm-146272).

Minimum attributes to record:

- Date
- Location of trapping session
- Where trapped (roost number)
- Weather
- Observer
- Whether a bat was a recapture or an untagged bat
- Band or transponder tag number, or location of fur clip on body
- Age, sex and reproductive class of all bats caught
- Numbers of bats present at the roost on the night bats were captured and the number caught

Record field observations on a paper form (see ‘Bat specimen record form’—docdm-141173), then store data in a computer-based spreadsheet.

Data storage

Forward copies of completed survey sheets to the survey administrator, or enter data into an appropriate spreadsheet as soon as possible. Collate, consolidate and store survey information securely, also as soon as possible, and preferably immediately on return from the field. The key steps here are data entry, storage and maintenance for later analysis, followed by copying and data backup for security.

Summarise the results in a spreadsheet or equivalent. Arrange data as 'column variables', i.e. arrange data from each field on the data sheet (date, time, location, plot designation, number seen, identity, etc.) in columns, with each row representing the occasion on which a given survey plot was sampled. Columns in the spreadsheet should include all data recorded on the original field sheet because the influences of factors such as location, observer, weather, etc., need to be accounted for in any analysis.

If data storage is designed well at the outset, it will make the job of analysis and interpretation much easier. Before storing data, check for missing information and errors, and ensure metadata are recorded.

Storage tools can be either manual or electronic systems (or both, preferably). They will usually be summary sheets, other physical filing systems, or electronic spreadsheets and databases. Use appropriate file formats such as .xls, .txt, .dbf or specific analysis software formats. Copy and/or backup all data, whether electronic, data sheets, metadata or site access descriptions, preferably offline if the primary storage location is part of a networked system. Store the copy at a separate location for security purposes.

Analysis, interpretation and reporting

Seek statistical advice from a biometrician or suitably experienced person prior to undertaking any analysis.

This method measures:

- Estimates of population size

Four approaches are possible for analysing data and reporting population estimates:

1. Calculating very simple estimates (minimum number of bats alive (MNA) following a recapture session). This is a crude technique that is not recommended unless there is no other way of obtaining information on population size. Results should be viewed with caution. A correlation between more rigorous population estimates and MNA has been reported in several small mammal studies (Hanley & Barnard 1999; Ruscoe et al. 2001) and two studies of long-tailed bats (Eglinton Valley and Hanging Rock; Pryde et al. 2005, 2006). However, in a third study of long-tailed bats, MNA greatly underestimated total population size (Grand Canyon Cave, near Piopio; Pryde et al. 2006).
2. Deriving population estimates from short-term sampling of closed populations (i.e. where there is no birth, death, immigration or emigration during the study) and obtaining an estimate of

absolute abundance. Closed-population methods are recommended if a single estimate of abundance is required. Analysis is relatively simple. No computer program is needed for analysis, just a calculator to solve several simple equations. There are a range of simple population estimators available. These are derived from the Lincoln-Petersen Estimator. This is described later in 'Full details of technique and best practice' because it is the simplest estimator to use.

3. Using the recapture probabilities calculated in open-population models to estimate population size. The Cormack-Jolly-Seber (CJS) model is the most commonly used method of analysis. Analysis of mark-recapture data can be computer-intensive and is aided by the use of specialist software. Program choice may depend on several things, including how well the program is supported in the literature, its user-friendliness, and the costs involved in obtaining the program. Program MARK is arguably the most comprehensive software available for mark-recapture analysis at the time of writing. It is described in more detail by Pryde (2003) and O'Donnell (in press). If capture histories are to be constructed for analysis in program MARK, the data are usually coded in binary form, e.g. 100010100, with years in which bats were recaptured coded '1', and '0' if they were not seen. In this example the bat was seen in the 1st year of the study but not in the following 3 years (coded '0'), seen again in the 5th year and 7th year but not in the 6th, 8th or 9th year. These encounter histories can have specifiers for age, sex and band number added to them (see Pryde 2003).
4. Using robust design models that combine elements of both open- and closed-population modelling. The robust model provides more precise abundance estimates when calculating multiple estimates of abundance. Program MARK is available for this analysis (Cooch & White 2004).

Data management and setup are described in more detail in 'Bats: trapping at roosts—estimating survival and productivity' (docdm-590867) and Pryde (2003).

Results are usually presented as population estimates plus a measure of error (e.g. confidence intervals). These can be tabulated (e.g. see Table 1 in 'Case study A') or graphed (e.g. Fig. 1).

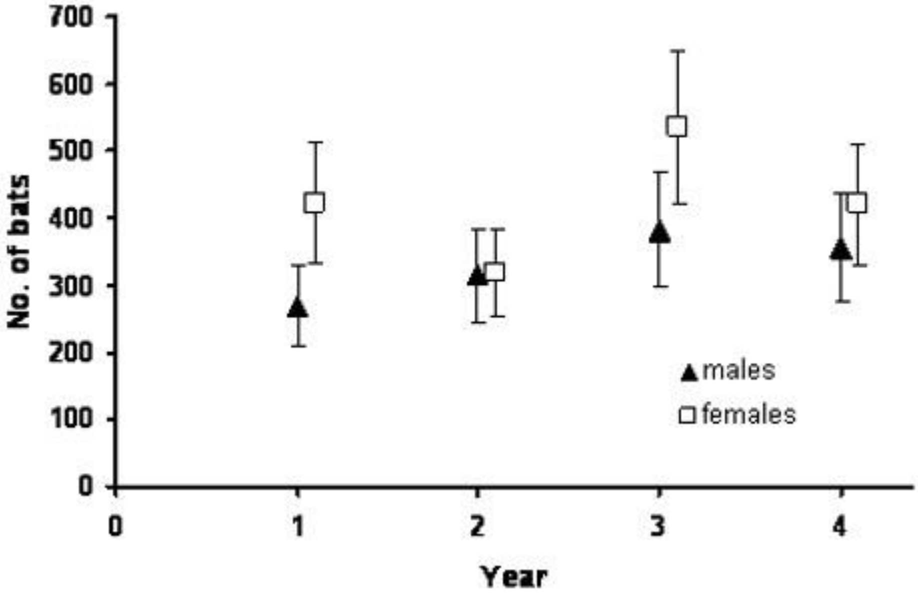

Figure 1. Annual population estimates ($\hat{N}$) for male and female long-tailed bats at Grand Canyon Cave, near Piopio, 1999–2003. Error bars represent 95% confidence intervals (from Pryde et al. 2006).

Seek advice of a statistician with expertise in modelling populations before undertaking mark-recapture studies to ensure the correct approach is used, because all approaches have set assumptions that should be met. There are strengths and weaknesses in each approach. Violating the different assumptions will have different consequences, which may influence the precision of population estimates and hence the conclusions drawn from analyses. Standard text books should be consulted to provide guidance on the precise formulae that should be used for calculating both the population estimate and the variance (e.g. Seber 1982; Thompson et al. 1998; Williams et al. 2002). Issues that need consideration are (a) whether there has been one or several recapture sessions, (b) how large the sample size is, and (c) whether additional bats were marked during subsequent recapture sessions. Fundamental requirements are to carefully examine whether assumptions of the methods are fulfilled and to estimate error rates (e.g. confidence intervals) to obtain some sense of the precision of the estimate. All estimates should be viewed with some caution and treated as just a general estimate of population size at the time of mark-recapture because estimates do not account for emigration, immigration, birth, death or other factors influencing survival.

Case study A

Case study A: using temporary marks and the Lincoln-Petersen Estimator to estimate population size in lesser short-tailed bats in the Eglinton Valley, Fiordland

Synopsis

Lesser short-tailed bats were rediscovered in Eglinton Valley, Fiordland in 1997 (O'Donnell et al. 1999) making it one of only three South Island populations of this threatened species.

Objectives

- To estimate the population size with confidence.
- Assess the performance of the population over time (status and trend) in relation to pest control operations being undertaken in Eglinton Valley.
- Compare population estimates derived from mark-recapture using the Lincoln-Petersen Estimator with counts of bats exiting individual roosts derived from camera and video counts.

Sampling design and methods

Bats were caught in harp traps as they emerged from their maternity roosts in January and February 2005. The mark-recapture method depended on temporarily marking a relatively large sample of bats, with the aim of marking > 40% of the population. However, in order to minimise stress on the bats, they were caught and processed in relatively small batches. Bats were counted as they fell into the trap using an infrared camera mounted on the trap. Once 40–80 bats were caught, the trap was lowered, emptied and then raised to the roost again to catch some more. The age and sex of each bat were recorded, and each bat was marked by shaving a small area of fur from the base of its back using a hair trimmer (Fig. 2). The bats were then released.

Four capture sessions were undertaken—one for the initial capture and three subsequent recapture sessions. The method depended on having a large number of skilled bat handlers and recorders present so that handling time for each bat was minimised. A minimum of 12 people were used per capture session and each person was assigned to a specific task (managing the trap, placing bats in holding bags, processing bats or recording). Thus, the whole operation lasted < 2 hours and individual bats were held for much shorter periods.

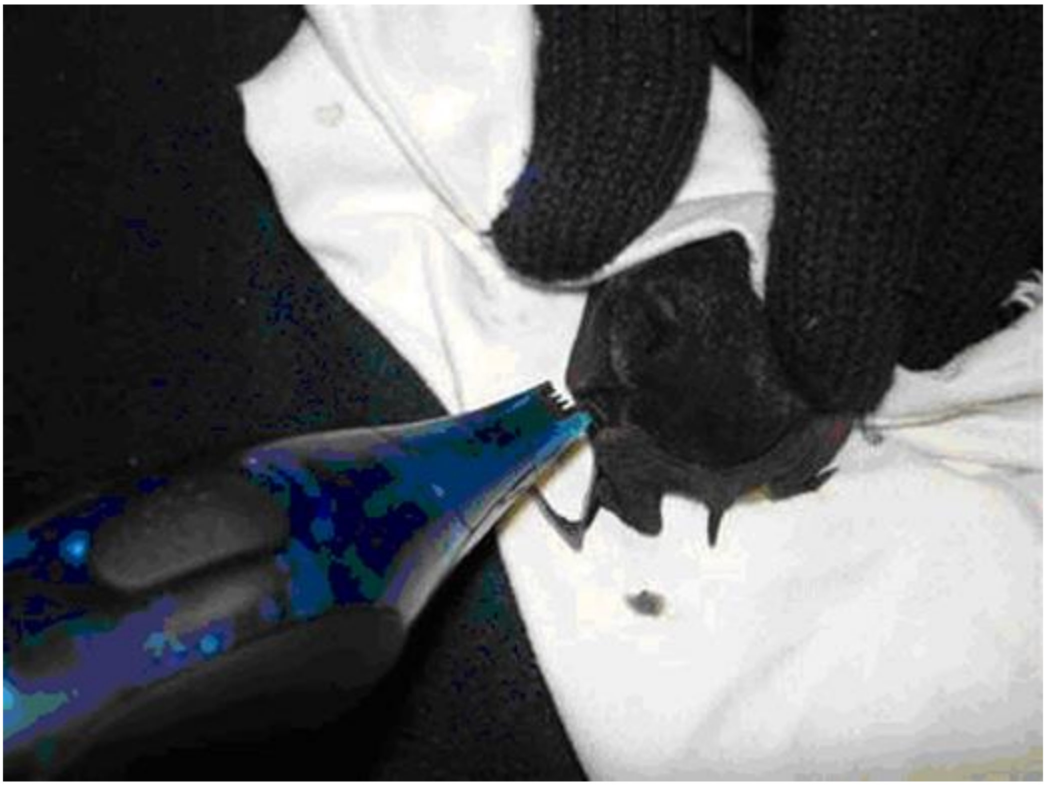

Figure 2. Temporarily marking a lesser short-tailed bat using a hair-trimmer to shave a small patch of fur.

Results

Estimates of between 1287 and 1848 lesser short-tailed bats were obtained (Table 1). These population estimates were far higher than the numbers of bats counted emerging from the individual roosts using the infrared cameras and video recorders, indicating turnover of individuals in the communal roosts.

Limitations and points to consider

Population estimates from the various recapture sessions varied markedly from each other and each estimate had a reasonably wide confidence interval. This variability largely resulted from not being able to mark individual bats with unique marks. The team's next challenge is to determine which of the estimates was more realistic (the higher or lower estimates) and whether consistent estimates can be obtained over time. The key to interpreting such results is to be sure that only one intermixing population was being sampled, then ensuring that only comparable samples are used in the analysis.

On examining the composition of different samples, it was apparent that recapture sessions 1 and 2 might not have been representative of the bat population. In the original capture session, adult males, adult females and juveniles (with an equal sex ratio) each made up approximately one third of captures. In recapture session 1, more juveniles were caught, and in recapture session 2, (less than a month later) virtually no juveniles were captured. Thus, it was concluded that recapture session 3 (Table 1) gave the most realistic estimate of population size, because (a) sample size of marked bats was high, and (b) the sex and age composition was representative of the equal sex ratios known from the population (similar to the original capture session).

Table 1. Population estimates for lesser short-tailed bats in the Eglinton Valley during post-lactation using the Lincoln-Peterson Estimator ± 95% CI, January–February 2005 (C. O'Donnell, unpubl. data).

Recapture session	Total No. marked *M*	No. existing roost*	No. caught *n*	No. of recaptures *m*	Population estimate *N*
1	259	835	179	26	1783 ± 323
2	259	726	157	22	1848 ± 368
3	394	468	199	60	1287 ± 138

* Recorded with infrared camera and video recorder.

The rapid sampling protocols adopted and the large number of captures demonstrates it is possible to obtain population estimates for lesser short-tailed bats using temporary marks, although how realistic these estimates were has yet to be determined. Critical examination of whether the samples were representative of the total population is essential. These estimates have yet to be calibrated against bat populations of known size in New Zealand (because alternative marking methods are not yet available). In addition, infrared video counts of bats emerging from roosts where the mark-recapture estimates were derived underestimated total population size markedly during this study (Table 1). The only way to achieve an accurate population count with videos is by counting bats emerging from all roosts occupied by the population simultaneously in one night.

References for case study A

O'Donnell, C.F.J.; Christie, J.; Corben, C.; Sedgeley, J.A.; Simpson, W. 1999: Rediscovery of short-tailed bats (*Mystacina* sp.) in Fiordland, New Zealand: preliminary observations of taxonomy, echolocation calls, population size, home range, and habitat use. *New Zealand Journal of Ecology 23*: 21–30.

Full details of technique and best practice

Choosing appropriate methods for marking

Mark-recapture studies are dependent on being able to apply recognisable marks to bats that last for the duration of the study. Marks must be applied ethically and humanely. Permanent marks that require recapture and rehandling of bats include forearm bands (long-tailed bats only) and Passive Integrated Transponder tags (PIT tags or 'microchips' for lesser short-tailed bats). Transponders show great promise as a marking technique because bats can be 'recaptured' without rehandling using automatic transponder readers located at a representative number of roost entrances. This helps to ensure high recapture probabilities. If information on number of bats with tags emerging at dusk is used in conjunction with a simultaneous video count at the same roost (total number of bats emerging), a coarse, one-off population estimate can be calculated (e.g. using the Lincoln-Petersen Estimator).

Population estimation using robust design models for open populations may also become feasible. Fur-clipping using a single, small clip is currently the only approved technique for short-term mark-recapture of lesser short-tailed bats in New Zealand. Other techniques, such as marking with permanent hair dye, require too much time to apply when handling a large number of bats. Temporary stains and dyes are groomed off by the bats too quickly. The dyes might contain harmful ingredients that could be ingested by the bats.

Trapping and handling methods

Anyone wishing to catch and handle bats must hold appropriate permits, have animal ethics approval and should be familiar with the potential health and safety issues associated with handling bats. For more information on such requirements contact the DOC Bat Recovery Group leader or the DOC conservancy bat contact (see ‘Bat Recovery Group contacts’—docdm-132033).

Full details of best practice for trapping, capturing, handling, marking and tracking bats are described in the ‘DOC best practice manual of conservation techniques for bats’ (docdm-131465). This section provides an overview of the trapping process. Initially, a suitable colonial roost is found using radio-tracking. A suitable roost is one in which all young have become independent, and the entrance is in a position on a tree where lines can be hoisted and the trap raised without being caught on the tree or disturbing the bats. A trap is then positioned in front of the roost exit with the catch bag c. 30 cm below the entrance. Bats are caught as they emerge at dusk. Once the trap is lowered, bats can be placed directly into cloth holding bags, and then processed.

If a large number of bats are required for a sample, which is the case when estimating population size in lesser short-tailed bats using the Lincoln-Petersen Estimator, then the trapping technique needs to be varied. If the colony is thought to number > 100 bats, then an infrared video camera linked to a screen is either secured to the trap or used from the ground so that bats can be counted as they fall into the trap. Once 40–80 bats are caught, the trap is lowered quickly to the ground. This means that not too many bats stay in the trap at one time. If more bats are needed for the sample, the catch bag is taken off and placed on legs near the people processing the bats. Another empty bag is placed on the trap and hoisted again to the roost (repeating the process so that c. 200–300 bats are caught in a sample). Meanwhile, the bats that are caught are placed in small holding bags by people dedicated to this task. These bats are passed to the people doing the processing. Each bat is weighed, sex and age are recorded, and a small fur clip is shorn from the bat’s back (right or left shoulder, or right or left lower back). The clip should be deep enough to remove the different coloured over-fur, but not reach the skin. Bats are released immediately. Roles of staff need to be clearly defined before the capture session so that the operation runs quickly and smoothly.

Lesser short-tailed bats have now been tagged successfully using transponders inserted under the skin, and preliminary trials using automatic tag readers and data loggers positioned at the roost hole have been successful at recording the number of bats with tags exiting the roost. Thus, in the future, it may not be necessary to physically recapture bats with transponders (Sedgeley & O’Donnell 2006, 2007). However, initial capture sessions (to insert transponders in the first instance) will need to follow the same protocols outlined above.

Minimising disturbance

Bats are disturbed by catching, handling and applying marks, and when they have to be recaptured subsequently to record their marks, they are disturbed yet again. Thus, caution and care need to be used when catching animals. In the Eglinton Valley, there is no evidence that catching bats at their roosts causes them to abandon a tree if best practice is strictly adhered to (Sedgeley & O'Donnell 1996). However, some bat species overseas are known to abandon their roosts if disturbed. Some lesser short-tailed bat colonies number several thousand individuals. It is inappropriate and unnecessary to catch all bats in such roosts. It is essential to have a large number of skilled bat handlers and recorders present so that handling times of bats is minimised. The authors recommend a minimum of 12 people per session, each assigned to different tasks (managing the trap, placing bats in holding bags, processing bats or recording). Thus, the whole operation runs efficiently, lasts < 2 hours, and individual bats are held for short periods (< 30 min). Roosts must not be trapped during periods when there are dependent young present in the colonies. This ensures lactating females can feed their young and avoids the risk of females abandoning their young.

Selecting an appropriate analysis technique

Practitioners should consider the objectives of their study, degree of precision they require, resources available, behaviour of their study animal, and whether the assumptions of analysis models can be met before choosing a method. Summing the minimum number of animals alive after capture sessions is relatively crude when compared with the population estimates that can be calculated. Simple mark-recapture methods using temporary marks are appropriate for mark-recapture analysis when (a) bats cannot be permanently or individually marked, (b) an estimate of population size is required, and (c) assumptions of the method are not violated. They are appropriate for short-term studies in closed populations (i.e. when the population is constant in size and composition during the study period—it is geographically and demographically closed with no births, deaths, immigration or emigration). Standard text books should be consulted to provide guidance on the precise formulae that should be used for calculating both the population estimate and the variance (e.g. Schemnitz 1980; Seber 1982; Thompson et al. 1998; Williams et al. 2002). Issues that need consideration are (a) whether there has been one or several recapture sessions, (b) how large the sample size is and, (c) whether additional bats were marked during subsequent recapture sessions. Radio-tagging of bats is best suited for monitoring survival of a limited sample of individuals through a management operation over the short term.

Minimum number alive

Calculation of simple estimates of survivorship is possible. For example, the minimum number alive (MNA—the number of individuals detected during that survey plus any additional animals detected in subsequent surveys) and proportion of a particular cohort alive can be calculated between sampling periods if animals are marked individually. For example, if 50 different bats were caught during an initial capture session during the breeding season, then MNA for Year 1 = 50 bats. If 30 of these bats were recaptured in Year 2 and 12 new juveniles were marked, MNA at Year 2 = 42 bats. In Year 3, if 25 marked bats were recaptured, but three of them were bats marked in Year 1 but not recaptured in Year

2, then clearly, they were still alive in Year 2. So, in this case, the MNA estimate for Year 2 should be revised: MNA = 42 + 3 = 45 bats in Year 2.

Lincoln-Petersen Estimator

The Lincoln-Petersen Estimator (also known as the Lincoln Index) is the simplest and most widely used mark-recapture abundance estimator for closed populations. This estimator applies to two sampling occasions at the roosts when animals are marked on the first occasion and re-sampled just once. Other estimators can be used if there are several capture sessions, if sample size is small, and if additional animals are marked during subsequent recapture sessions. The Lincoln-Petersen estimator is most likely to be used for monitoring short-term survival through management operations.

The basic index is easy to calculate. It provides an estimate of the population size and a measure of variability around the estimate. Solve the equation (from Schemnitz 1980):

$$N = M \frac{n}{m_2}$$

where

N = estimated population size

n = number caught at time 1

M = number caught at time 2

m_2 = number of recaptures

An approximate 95% confidence interval for this estimate is given by:

$$\text{SE} = \sqrt{\frac{M^2 n(n-m)}{m^3}}$$

There are many variations and some improvements to these equations (e.g. see Seber 1982; Thompson et al. 1998; Williams et al. 2002), some of which are important if multiple recapture sessions are undertaken. However, estimators have yet to be calibrated against known size populations.

When analysing results, it is essential to consider whether the assumptions have been met. Two factors are particularly important. Firstly, lesser short-tailed bat colonies switch roost sites frequently. Secondly, not all bats in a population occupy the same roost tree on the night of sampling. All animals need to have the same probability of being caught. Radio-tracking of lesser short-tailed bats in the Eglinton Valley revealed that individuals appear to move almost at random among a pool of about 20 colonial roosting trees in the breeding season (Sedgeley 2003; Christie 2003). Therefore, in this area we were confident that individuals caught in the Eglinton Valley are from just one population, even though subsequent capture sessions might have happened at different roosts. The composition of captures in the initial and subsequent samples should be checked to ensure that the proportions of each age and sex class are similar.

Estimating population size using recapture probabilities from open populations

If recapture probabilities are high, and the assumptions of the model are met, then the recapture probabilities calculated from these models can be inserted in the equations for estimating population size. There are many options for estimating population size. Put most simply, once capture probability is known, population sizes for each capture occasion (denoted as *i*) can be estimated by the equation:

$$\hat{N}_i = \frac{n_i}{\hat{p}_i}$$

where

$\hat{N}_i$ = estimated number of animals captures on occasion i

n_i = number of animals captured on occasion i

$\hat{p}_i$ = estimated capture probability on occasion i

An approximate 95% confidence interval for this estimate is given by:

$\hat{N}_i \pm 2\sqrt{\text{var}(\hat{N}_i)}$, and

$\text{var}(\hat{N}_i) = \frac{n_i^2 \, \text{var}(\hat{p})}{\hat{p}_i^4} + \frac{n_i(1-\hat{p}_i)}{\hat{p}_i^2}$ (Williams et al. 2002, p. 503).

Recruitment between capture sessions is then estimated according to the equation:

$$\hat{B}_i = \hat{N}_i - \phi_i \hat{N}_{i-1}$$

where

$\hat{B}_i$ = recruitment for occasion i

$\hat{N}_i$ = population size for capture occasion i

ϕ_i = survival probability on occasion i

The robust design

Combination of features of both open- and closed-population models is made possible by structuring capture occasions into primary and secondary periods; this results in a 'robust design' (Lettink & Armstrong 2003). For example, a trapping study might involve trapping animals for 5 consecutive nights every year for 10 years, where the year interval is the primary period and the 5 consecutive nights the secondary periods. From such a study, it will be possible to estimate population size for each of the annual 5-night trapping sessions using closed models, and survival rates for the nine intervals between the 10 years using open-population model techniques. The assumptions of open-population models also apply to use of the robust design, with one major difference. Meeting the assumption of equal probability of recapture becomes less important as this design is robust to capture heterogeneity and/or trap response (Pollock 1982). Other advantages of using the robust design are increased precision for population estimation compared with using an open-population model alone, and the ability to estimate births or immigration separately. The disadvantage is that the robust design requires more resources because more sampling periods are required than when using either open- or closed-population models alone.

Data management and setup are described in more detail in 'Bats: trapping at roosts—estimating survival and productivity' (docdm-590867) and Pryde (2003).

References and further reading

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Appendix A

The following Department of Conservation documents are referred to in this method:

docdm-132033	Bat Recovery Group contacts
docdm-141173	Bat specimen record form
docdm-590733	Bats: counting away from roosts—automatic bat detectors
docdm-590701	Bats: counting away from roosts—bat detectors on line transects
docdm-590867	Bats: trapping at roosts—estimating survival and productivity
docdm-131465	DOC best practice manual of conservation techniques for bats
docdm-146272	Standard inventory and monitoring project plan