Birds: estimates of absolute density and abundance—mark-resight for closed populations

Version 1.0

This specification was prepared by Terry Greene in 2012.

Contents

Department of Conservation
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Synopsis

Whenever individual birds can be captured, marked, released and a proportion of these individuals can be recaptured from a clearly defined, demographically and spatially closed population, population size can be estimated using the ratio of marked to unmarked individuals. However, it is not necessary to capture, handle and mark birds after the first sample occasion if marked individuals can be identified without being recaptured. Marking systems suitable for this method include coloured leg bands and radio-transmitters. White (1996a,b) developed the program NOREMARK[1] to calculate population estimates based on resightings of individually marked animals. Four estimators of abundance are provided along with simulation routines to assist with the design of mark-resight sampling programmes. The main limitation of this method is that unmarked birds cannot be marked on subsequent occasions, thereby constraining sample size and reducing estimate precision. However, the advantage of this procedure is that resighting is cheaper than physically catching and handling birds of most species. Like other closed-population estimation methods, mark-resight procedures only have practical application in situations where objects of interest are common (cf. rare and/or thinly distributed), reasonably sedentary (e.g. territorial bird species or those that tend not to move over large areas), found in discrete habitats (e.g. discrete patches of forest, islands), or immobile objects like nests and where radio-telemetry is feasible (Thompson et al. 1998).

Assumptions

- All birds have the same probability of being caught. Care is obviously required when defining initial geographic sampling coverage.
- The population is closed, i.e. no births, deaths, immigration or emigration during the study. One of the models within program NOREMARK allows partial relaxation of this assumption (the study area does not need to be geographically closed).
- Resighting probabilities can vary by ‘sighting’ occasion and each animal can have its own capture probability providing that it is constant across occasions. (This assumption can be extremely problematic in practice.)
- Marks are not lost and the probability of sighting a bird is not affected by capture, handling or marking.

Advantages

- High precision is commonly achieved (CV < 15%), provided assumptions are met and sampling design is robust.
- Analysis of data is straightforward. Program NOREMARK is easy to use and does not take long to learn.
- It is very useful for geographically well-defined populations of highly visible birds with restricted ranges (e.g. islands or discrete habitats).

[1] http://welcome.warnercnr.colostate.edu/~gwhite/software.html

- It is often a cost-effective field application compared with other mark-recapture methods. However, there are situations where it is far from easy to collect resighting information and one would be better to rely on recaptures.
- There is potential for less resighting heterogeneity (i.e. variations in resighting probabilities)—something that plagues standard mark-recapture population estimators. However, it should be noted that the robustness of resighting estimates to breaches of assumptions (including individual heterogeneity) has not been fully documented. The recent development of a beta-binomial mark-resight estimator (BBE) (by McClintock et al. 2006) goes some way to addressing these concerns.

Disadvantages

- Each bird has to be individually identifiable.
- A high percentage of the population needs to marked within the defined sampling area to ensure precision. The marked population needs to be maintained if mark-resight methods are to be used over long periods.
- The number of resighting occasions required is dependent on the proportion of the population marked and the proportion of marked birds seen on each sampling occasion. In practice, the number of resighting surveys needs to be relatively high (7+) to ensure good estimate precision (e.g. CV < 15%).
- Closure assumption is violated in very mobile populations or populations with many transient individuals.
- Resighting is still subject to behavioural variation. Familiarity with marked animals risks increasing their resighting probability.
- Currently there is no means to objectively select models (e.g. Akaike's Information Criterion (AIC)) within program NOREMARK and the BBE model is yet to be incorporated within this framework. Alternative analyses are likely to be very messy!

Suitability for inventory

Mark-resight sampling demands robust survey design, attention to potential violation of critical assumptions and specialist analytical skills. Resource costs (labour and money) can be significant and the data obtained are often beyond those required for simple inventory. For these reasons, mark-resight sampling is not recommended for compiling simple species inventories.

Suitability for monitoring

Provided all critical assumptions can be met and sufficient resources are available, mark-resight sampling methods can provide accurate estimates of abundance for populations of birds. Comparisons of robust abundance estimates over time and across space are therefore possible and this is an obvious advantage for monitoring programmes where the primary objective is to detect trends in population size. Another advantage of mark-resight sampling is the flexibility with which it can be applied within various terrain types, habitats and target species behaviours.

Although mark-resight methods are unlikely to be suitable for monitoring very rare or sparsely distributed bird species, relatively small populations can be estimated (depending on the precision required) provided the resighting probability per occasion is > 0.4 and number of resighting occasions can be increased.

Skills

Field workers must be able to:

- Recognise the species of interest and be competent in reading the individual marking system being used.
- Capture, handle, measure and mark the species of interest in a competent and ethical manner according to the relevant guidelines.
- Understand the relevant sampling design issues (particularly the definition of survey area), the assumptions of mark-resight methods and the options available to improve the accuracy and precision of population estimates.
- Identify potential violations of assumptions and the consequences for calculated abundance and variance estimates.
- Cover the intended sample area safely, with equal search intensity, within the time allocated.
- Analyse the collected data using the relevant computer software (e.g. NOREMARK).

Resources

All mark-recapture methods are expensive compared with most other population estimation techniques. However, the expense can often be justified by the increased precision of population estimates (at least for closed populations) provided the assumptions can be met. Generally speaking, trapping birds is expensive both in terms of equipment (nets, traps, marks, etc.) and the time required to set up and run the traps. The cost of individually marking birds can range from relatively cheap methods (metal and coloured plastic leg bands) through to much more expensive marking systems such as radio-tags. A comprehensive list of marks or marking systems can be found in Bibby et al. (2000). If radio-tags are to be used, the cost of receivers and antennae (c. $3,000/unit), in addition to the tags themselves ($150–300+), needs to be factored in.

Personnel costs can also be significant when surveying for marked birds, particularly if the birds are relatively rare and/or are likely to be scattered over large areas. In addition to the proportion of the population that is marked (ideally at least 40%), the precision of abundance estimates is dependent on the number of sighting occasions within the sample area. As a rule of thumb 6–8 surveys are required, the costs of which need to be factored in.

Equipment for resighting surveys is relatively inexpensive in comparison, requiring only maps of the survey area, binoculars, data sheets, notebook, pens or pencils, and the means of moving within and between survey areas (usually a pair of legs). Resources should also be set aside for analysis and statistical advice.

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:

- Record metadata, including observer's name and contact details, date, route and number of each resight survey, time over which survey conducted (start/finish times) and weather details (rain, cloud, wind, temperature, sunshine minutes, noise).
- Record location (preferably with spatial attributes) of sampling frame.
- Identify which individuals the 'marked' population consists of. These individuals can be designated later if the population is already marked (see 'Case study A').
- Record number of all birds seen on each survey occasion. Designate all birds seen as either 'marked and identified', 'unmarked' or 'marked but identity unknown'. The identity of all marked birds seen must be recorded.
- Data should be saved as a text file and imported into NOREMARK for analysis.

Data storage

Copies of completed survey sheets and appropriate metadata should be forwarded to the survey administrator and entered into a 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.

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

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.

Analysis of mark-resight data should be conducted within the software program NOREMARK. Enter results into a spreadsheet in such a way that they can be either imported directly into NOREMARK as an '.inp' file or be summarised so they can be entered manually. Once the analysis model, the alpha level for confidence level construction (typically = 0.05), number of sighting occasions and data have been entered, analysis can proceed. Outputs from the program are relatively easy to interpret, although information will vary slightly depending on the chosen analysis model. Typically, an estimate of the minimum number known to be alive (MNA), total population estimate and confidence interval on the total population estimate is produced and easily located.

White (1996b) provides a detailed reference manual and user's guide to the analysis of mark-resight data using program NOREMARK. Users are directed to this guide and its companion publication (White 1996a) for detailed descriptions of the available analysis models and their assumptions, simulation routines, explanations of analysis output and underlying mathematical theory.

Users of mark-resight methods should also be aware of and consider using the recently developed beta-binomial estimator (BBE) (McClintock et al. 2006). This closed-population abundance mark-resight model combines maximum likelihood theory and allowance of individual heterogeneity in sighting probability (*p*) and seems to be a reliable and more precise alternative (under certain conditions) to the joint hyper-geometric maximum likelihood estimator (JHE) and Bowden's estimator.

Case study A

Case study A: population estimates of black robin on Mangere and Rangatira islands using program NOREMARK

Black robin, Chatham Island. (photo: DOC).

Synopsis

Following the end of intensive monitoring of the entire black robin population on Rangatira and Mangere islands, a less intensive method was required to monitor population trends. Initial trials with distance sampling methods proved unsuccessful because robins were attracted to observers, resulting in large overestimates of population size (R. Hay, pers. comm.). As a very high percentage of the black robin population on both islands was still banded, it was decided to conduct a trial of a closed-population mark-recapture estimator based on resightings (rather than recaptures) of marked individuals. Comparisons of the accuracy and precision of these estimates derived from program NOREMARK could then be made with recent known population estimates derived from the banded population and territory mapping.

Objectives

- Are mark-resight methods a viable means of monitoring black robin population abundance on Rangatira and Mangere islands?
- How many black robins are present within the sampled area on Mangere and Rangatira islands and are any trends apparent over the period 2002–04?

Sampling design and methods

This study was essentially a pilot study designed to assess the suitability of mark-resight estimators as a means of monitoring black robin population trends.

Program NOREMARK (and mark-resight methods generally) assumes the marked birds seen on the first sampling occasion are considered to be the marked population for the survey and have been drawn randomly from the population (White 1996a,b). As the majority of black robins on both Rangatira and Mangere islands were individually colour banded prior to the commencement of this study, it became necessary to designate which individuals were to be treated as 'marked' and which as 'unmarked'.[2] Simulation suggested that a minimum sample of 15–20 'marked' black robins (approx. 40% of the population within each study area) and a minimum of seven sampling occasions during each survey period would be required to accurately estimate population size with reasonable precision. To achieve this, an initial sweep through defined study areas (in this case reasonably discrete patches of forest) prior to every survey period was conducted. In most instances, all birds identified in this initial survey were labelled as 'marked' but this information was withheld from fieldworkers to avoid biasing sightings towards notionally 'marked' birds. During each subsequent sampling occasion observers attempted to record as many 'marked' and 'unmarked' black robins whilst moving systematically throughout the study area.

Both study sites contained areas of high seabird burrow density which, in practice, often meant access was restricted to a network of established routes and tracks. Most resighting surveys were

[2] This is necessary as a list of marked individuals definitely known to be present within the sampling area is required at the start of the survey period. Given the remote location of the islands, this could only be achieved by conducting an initial survey of the robin population on arrival and 'selecting' (randomly, first detected, etc.) those to be treated as marked.

conducted during the morning when robin conspicuousness was at its highest. Surveys were only attempted in amenable weather conditions in the absence of rain and/or high wind. Observers did not feed or deliberately attract robins (e.g. by clapping) during surveys in an attempt to ensure equal resighting probability and minimise double counting of 'unmarked' birds.

In Robin Bush on Mangere Island (the only habitat suitable for black robins) eight sampling occasions were conducted during each of the September 2002 and March 2003 survey periods. An additional nine sampling occasions were undertaken during September 2003 and ten more in September 2004. Initially, sampling was undertaken in the afternoon, but, as bird conspicuousness was low, this was changed to morning surveys.

Surveys of Rangatira Island were restricted to the Woolshed and Island Bush areas where the bulk of the black robin population was concentrated. Eleven sampling occasions were completed in the September 2002 survey, eight in March 2003, ten in September 2003 and nine in the September 2004 survey.

Data collection

The following documents contain examples of data sheets used for this study:

- 'NOREMARK black robin sheet' (docdm-412513). This document is a sheet on which to record black robin data.
- 'Black robin data example' (docdm-412468). This document contains an example of the information required for the JHE and the Bowden's estimator.

Results

An example of the preliminary population estimate generated by NOREMARK for black robins on Rangatira Island in September 2002 is shown in Table 1.

Table 1. Black robin population estimates for Rangatira Island 2002.

Pre-breeding season—Rangatira September 2002
JHE mark-resight population estimate for closed populations
Alpha level for confidence interval construction: 0.05
Number of re-sighting occasions: 10

Occ	marked available	marked seen	unmarked	Lin- Pet	95%CI
1	20	10	28	75.4	48.8–98.1
2	20	10	18	54.4	37.3–71.4
3	20	6	21	83	41.8–124.2
4	20	12	14	47.5	32.5–52.8
5	20	8	29	92.3	51.4–124
6	20	11	28	69	48.2–89.8
7	20	7	26	88.3	48.1–128.4
8	20	9	16	59.9	35.3–71.9
9	20	7	25	85.6	46.9–124.4
10	20	10	23	60.3	42.6–77.9

Population estimate: 71 **95% confidence interval 64–81**

JHE accumulative mark-resight population estimate for closed populations

Alpha level for confidence interval construction: 0.05

Number of re-sighting occasions:10

Occ	marked available	marked seen	unmarked	Lin- Pet	95%CI
1	20	10	28	73.5	50–100.8
2	36	15	13	66.1	50–82.1
3	42	12	15	91.6	62–121.3
4	47	17	12	71	56.2–85.8
5	49	15	24	117.8	82.3–153.2
6	54	24	15	87	71.7–102.3
7	60	18	15	108.2	81.8–134.5
8	63	17	8	91.4	71.9–111
9	63	12	20	161.5	102.3–220.6
10	67	17	16	127.4	93.5–161.4

Population estimate: 106 **95% Confidence interval 98–116**

A summary of preliminary estimates for both Mangere and Rangatira islands for all models from 2002 to 2004 is provided in Table 2 and graphed in Fig. 1.

Table 2. A summary of preliminary estimates for Mangere and Rangatira islands for all models from 2002 to 2004.

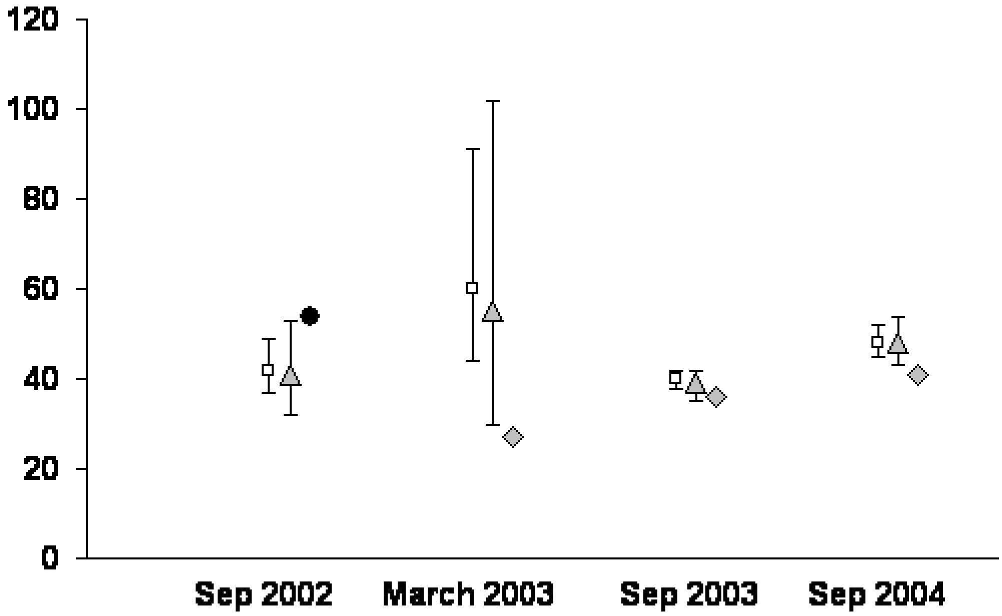
Mangere Island

	JHE estimate	Bowden's	Census
Sep 02	42 (37–50)	41(32–53)	54
Mar 03	60 (44–91)	55 (32–102)	
Sep 03	40 (38–42)	39 (35–42)	
Sep 04	48 (45–52)	48 (43–54)	

Rangatira Island

	JHE estimate	Bowden's
Sep 02	71 (64–81)	69 (55–87)
Mar 03	87 (77–102)	87 (69–108)
Sep 03	71 (66–79)	72 (59–86)
Sep 04	67 (62–75)	70 (58–85)

Mangere Island



Rangatira Island

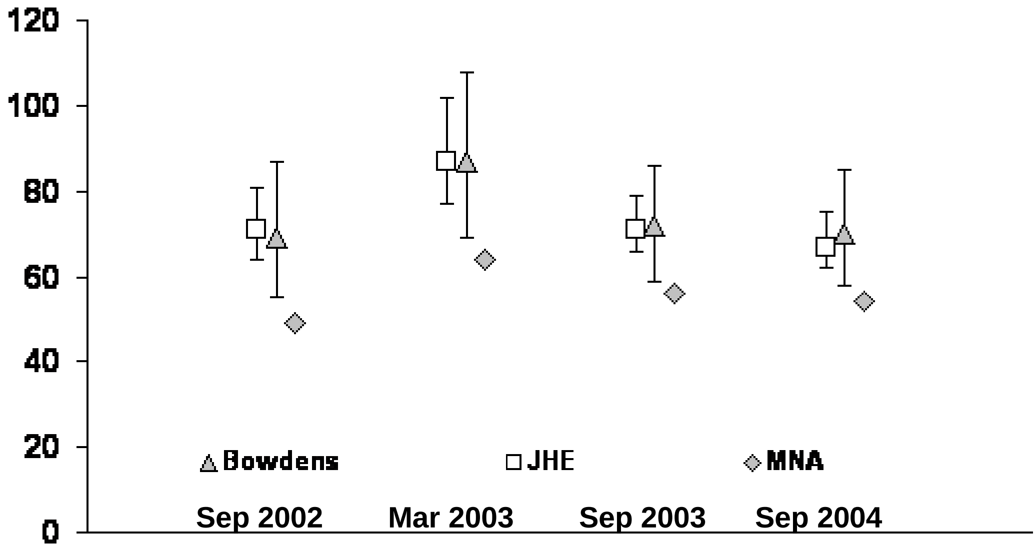


Figure 1. Preliminary population estimates for Mangere and Rangatira islands for all models from 2002 to 2004

Direct comparison of the population estimate and census result from Mangere Island in September 2002 suggested that both precision and accuracy of the mark-resight method were relatively poor.

Confidence interval length for this estimate using the preferred Bowden's estimator was 51%, with the census result just falling outside the upper 95% confidence interval. This suggests a degree of negative bias and a population underestimate. The precision of the population estimate for Rangatira Island was even worse, with a confidence interval length of 46% reported. It is unknown whether the results from Rangatira Island were negatively biased (no simultaneous census data were available), but there were no reasons to expect otherwise.

The sampling design was re-examined in view of these results. Improvements in the survey coverage of Robin Bush (new survey tracks) and a much higher ratio of marked to unmarked robins on Mangere Island resulted in immediate improvements to estimate precision. Confidence interval lengths were reduced to 18% in September 2003 and 23% in September 2004. However, on Rangatira Island the increase in precision was much less marked. There, confidence interval lengths reached only 37.5% and 38.6% for the same survey periods, despite survey coverage being extremely good. Poor population estimate precision on Rangatira Island was thought to be caused by the relatively low proportion of banded birds within the population being surveyed compared with that on Mangere Island.

Although Bowden's estimator was preferred over the JHE, the penalty for this was a general decrease in precision (larger confidence intervals). If the basic JHE model was chosen for its greater precision (smaller confidence intervals), the underlying assumptions are that each animal has the same probability of being resighted and the population is geographically and demographically closed. This was thought to be unrealistic as both Rangatira and Mangere islands are unlikely to ever be entirely closed as the birds are free to move into and out of the surveyed area. This was particularly the case on Rangatira Island where significant numbers of robins occur in adjacent forested areas. It was also thought that the resighting probability would be different for each bird (something the Bowden's estimator allows), given that many of them have been fed in the past.

Comparison of the September surveys between 2002 and 2004, for both study areas, did not show any significant population change between years for either the JHE or the Bowden's estimator. However, both estimators indicated an increase in the black robin population on Mangere and Rangatira islands between September 2002 and March 2003. This could reflect the expected post-breeding population increase and subsequent decline following winter mortality, or simply the large confidence intervals. The transfer of 14 black robins from Rangatira Island to Pitt Island in September 2002 (following the counts) was also reflected in the relatively small population increase seen on Rangatira Island between September 2002 and March 2003. The small population increase observed on Mangere Island between September 2003 and 2004 was thought to be an actual increase rather than an improvement in sampling methods given that no such increase was observed on Rangatira Island.

Limitations and points to consider

The precision and accuracy required to assess whether a population is increasing or decreasing is dependent on the survey effort (area covered, number of sample occasions, etc.), number of birds banded, probability of resighting a banded individual, precision required, time available and estimator used.

For long-term mark-resight based monitoring programmes, the proportion of marked birds within the study area will inevitably decline unless there is a regular mark-replacement programme. A decreasing number of marked birds will result in decreasing accuracy and precision, and eventually failure of the method to provide any useful information. At least two replacement strategies are possible: Firstly, a number of nests could be monitored every 2–3 years and a proportion of fledglings banded equal to the desired proportion of marks in the adult population. Thus the marked population can be maintained and productivity levels can be assessed along with more general measures of population demographics. Secondly, sufficient adults could simply be captured at intervals to maintain the required proportion of marks in the population. If the first (and more intensive) option is taken, the option of running a well-designed longitudinal capture-recapture-resighting study utilising open-population models should be considered.

Bowden's estimator and JHE are both useful models with which to assess population trends of a variety of species. However, as the JHE estimators assume that each animal in the population has the same probability of resighting on a particular occasion, care should be taken when interpreting results if significant numbers of black robins are known to approach observers or be more visible than others. The assumptions underlying Bowden's estimator and the recently developed BBE (McClintock et al. 2006) are likely to be more realistic for the majority of bird species.

It is worth noting that for most mark-recapture or mark-resight sampling methods that attempt to estimate population size over multiple surveys, it can be rather difficult to define what comprises the 'population'. Generally, we are measuring the population of animals that can be trapped, seen, or regularly use the survey area. If a number of animals have a very low probability of capture (or resighting), population sizes are usually underestimated.[3] These problems become much less of an issue when the study area encompasses the whole population.

References for case study A

Borchers, D.L.; Efford, M.G. 2008: Spatially explicit maximum likelihood methods for capture-recapture studies. *Biometrics 64*: 377–385.

Full details of technique and best practice

There is no generic best practice approach for mark-resight data collection and analysis as each species is likely to have its own set of optimal design and analysis parameters. Nevertheless, there are some general best-practice points to keep in mind:

- Some sort of pilot study is essential to determine (a) whether enough of the target species can be captured and marked, (b) the probability of resighting, (c) how many resighting occasions are

[3] For typical mark-recapture studies this can now be addressed using spatially explicit mark-recapture models (programme DENSITY—Borchers & Efford 2008). The problem still remains for mark-resight estimators.

required and (d) whether assumptions are satisfied. These data can then be inserted into the design simulation routines for the various models found within NOREMARK and an optimal design developed for a stated precision using the most appropriate model.

- The assumptions generic to all mark-resight methods and those specific to particular models must be examined critically and potential violations and sources of bias identified. More simulation studies would help to understand these problems.
- The sampling area from which the population estimate is to be derived must be well defined and understood by field operators and those responsible for analysis.
- The marks used on a given species must be clearly observable and individually distinguishable in the field by all field workers. Marks must not harm birds or affect their behaviour. Appropriate animal ethics approval must be given.
- Available resources must be sufficient to catch and mark sufficient individuals, as well as conduct the requisite number of resighting surveys. If the monitoring programme is to be maintained for a long time period, a mark replacement programme will be required.

References and further reading

Bibby, C.J.; Burgess, N.D.; Hill, D.A.; Mustoe, S. 2000: Bird census techniques. 2nd edition. Academic Press, London. 302 p.

Borchers, D.L.; Efford, M.G. 2008: Spatially explicit maximum likelihood methods for capture-recapture studies. *Biometrics 64*: 377–385.

McClintock, B.T.; White, G.C.; Burnham, K.P. 2006: A robust design mark-resight abundance estimator allowing heterogeneity in resighting probabilities. *Journal of Agricultural, Biological and Environmental Statistics 11*: 231–248.

Thompson; W.L.; White; G.C.; Gowan, C. 1998: Monitoring vertebrate populations. Academic Press, Inc., San Diego. 365 pp.

White, G.C. 1996a: NOREMARK: Population estimation from mark-resighting surveys. *Wildlife Society Bulletin 24*: 50–52.

White, G.C. 1996b: Program NOREMARK software reference manual. Department of Fishery and Wildlife Biology, Colorado State University, Fort Collins, CO.

Appendix A

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

docdm-412468	Black robin data example
docdm-412513	NOREMARK black robin sheet
docdm-146272	Standard inventory and monitoring project plan