

FW663 -- Laboratory Exercise

Mark-Resight Analysis with Program NOREMARK

Technologically advanced approaches to the problem of abundance estimation have incorporated animals marked with radio transmitters. The initial sample of animals is captured and marked with radios, but recaptures of these animals are obtained by only observing them, not actually recapturing them. The limitation of this procedure is that unmarked animals are not marked on subsequent occasions. The advantage of this procedure is that resighting occasions are generally much cheaper to acquire than when the animals must be physically captured and handled. The mark-resight procedure has been tested with known populations of mule deer (Bartmann et al. 1987), and used with white-tailed deer (Rice and Harder 1977), mountain sheep (Furrow et al. 1981, Neal et al. 1993), black and grizzly bears (Miller et al. 1987), coyotes (Hein 1993), and moose (Bowden and Kufeld 1995).

The objective of this exercise is to explore program NOREMARK, a program to compute mark-resight estimators of population abundance. Three estimators of abundance are provided: the joint hypergeometric maximum likelihood estimator (JHE) (Bartmann et al. 1987, White and Garrott 1990, Neal et al. 1993), the joint hypergeometric maximum likelihood estimator extended to incorporate animals moving on and off the study area (Neal et al. 1993, White 1993), the Minta-Mangel estimator (Minta and Mangel 1989), and Bowden's estimator for the Minta-Mangel model (Bowden and Kufeld 1995).

First, a section defining the mathematical notation will be presented, followed by a section describing the details of each of the estimators. Then, the startup of Program NOREMARK will be shown with annotated examples.

Notation

T_i	Number of marked (telemetered) animals in the population at the time of the i^{th} survey, $i=1,...,k$. When the number of marked animals is assumed constant across surveys, the value is denoted as T .
M_i	Number of marked animals in the population that are on the area surveyed at the time of the i^{th} sighting survey. For all M_i constant, define $M \equiv M_i$.
n_i	Number of animals seen during the i^{th} sighting survey, consisting of m_i marked animals and u_i unmarked animals, so that $n_i = m_i + u_i$.
f_j	Number of times marked animal j was observed during the k surveys (sighting frequencies), $k = 1, ..., T$.

$m.$ Total number of sightings of marked animals seen, so that $m. = \sum m_i = \sum f_j$.

$u.$ Total number of sightings of unmarked animals seen, so that $u. = \sum u_i$.

\bar{f} Mean capture frequency of marked animals, $m./T.$.

s_f^2 Variance of the sighting frequencies of the marked animals,

$$s_f^2 = \frac{\sum_{j=1}^T (f_j - \bar{f})^2}{T.} .$$

Estimators

Four estimators of population size for marking and sighting experiments are provided in Program NOREMARK. First is the joint hypergeometric maximum likelihood estimator (JHE) (Bartmann et al. 1987, White and Garrott 1990, Neal 1990, Neal et al. 1993). JHE is the value of N which maximizes the following likelihood (\hat{N}):

$$\mathcal{L}(N \mid M, n_i, m_i) = \prod_{i=1}^k \frac{\binom{M}{m_i} \binom{N-M}{n_i-m_i}}{\binom{N}{n_i}}$$

and the terms are defined for all $i = 1$ to k sighting occasions. The estimate \hat{N} can be found by iterative numerical methods. Confidence intervals are determined with the profile likelihood method (Hudson 1971, Venzon and Moolgavkar 1988). This estimator assumes that all the marked animals are on the area surveyed for each survey, i.e., that the population is geographically closed. Hence, the number of marked animals (M) is constant for each survey, although the sighting probability is not assumed to be constant for each survey.

Second, the JHE estimator has been extended to accommodate immigration and emigration (Neal et al. 1993) through a binomial process. This estimator is labeled IEJHE, and does not assume that the population is geographically closed. Assume that the total population with any chance of being observed on the study area is N^* , and that at the time of the i^{th} sighting survey, N_i animals occur on the study area. I am interested in estimating the mean number of animals on the study area, \bar{N} , and possibly N^* . At the time of the i^{th} sighting occasion, a known number of the marked animals (M_i) are on the study area of the possible T_i animals with transmitters. The probability that an individual is on the study area on the i^{th} occasion can be

estimated as M_i/T_i , or in terms of the parameters of interest as N_i/N^* . Then the likelihood for the model that includes immigration and emigration is a product of the binomial distribution for emigration/immigration times the joint hypergeometric likelihood of Eq. (1):

$$\mathcal{L}(N^*, N_i | T_i, M_i, m_i, n_i) = \prod_{i=1}^k \binom{T_i}{M_i} \left(\frac{N_i}{N^*} \right)^{M_i} \left(1 - \frac{N_i}{N^*} \right)^{T_i - M_i} \frac{\binom{M_i}{m_i} \binom{N_i - M_i}{n_i - m_i}}{\binom{N_i}{n_i}}$$

The parameters N^* and N_i for $i=1$ to k can be estimated by numerical iteration to maximize this likelihood, with the constraints that $N_i > (M_i + u_i)$ and $N^* > N_i$ for $i=1$ to k . Profile confidence intervals can be obtained for the $k+1$ parameters. I was not interested in the k population estimates for each sighting occasion, but rather desired the mean of the N_i estimates. Therefore, I re-parameterized the likelihood to estimate the total population and mean population size on the study area directly, and their profile likelihood confidence intervals. In the re-parameterized likelihood, I used $N_i = \bar{N} + \alpha_i$, where $\sum \alpha_i = 0$.

Third, Minta and Mangel (1989) suggested a bootstrap estimator (MM) of population size based on the sighting frequencies of the marked animals, f_i . For unmarked animals, sighting frequencies are drawn at random from the observed sighting frequencies of the marked animals until the total number of captures equals u . The number of animals sampled is then an estimate of the number of unmarked animals in the population, so that M plus the number sampled is an estimator for N . Only samplings where the number of sightings was equal to u were used, i.e., cases where the cumulative sightings exceeded u were rejected. Minta and Mangel (1989) accepted the first value where the cumulative sightings equalled or exceeded u . The stopping rule I used results in less bias than the rule used by Minta and Mangel (1989). Minta and Mangel (1989) suggested the mode of the bootstrap replicates as the population estimate. Confidence intervals were computed as probability intervals with the 2.5th and 97.5th percentiles from the bootstrapped sample of estimates. White (1993) demonstrated that the MM estimator is basically unbiased, but that the confidence interval coverage was not at the expected 95% for $\alpha=0.05$. He suggested a modified procedure, but coverage again was not adequate.

Fourth, Bowden and Kufeld (1995) suggested an estimator for the Minta-Mangel model where the confidence intervals on the estimate were computed based on the variance of the resighting frequencies of the marked animals. He approached the problem from a sampling

framework, where each animal in the population has the attribute f_i of the number of times it was resighted. The values of f_i are known for the marked animals, and the sum of the f_i 's (= $u.$) are known for the unmarked animals. Then, an unbiased estimator of the population size is

$$\hat{N} = \frac{\left(\frac{(u. + m.)}{\bar{f}} + \frac{s_f^2}{\bar{f}^2} \right)}{\left(1 + \frac{s_f^2}{T\bar{f}^2} \right)}$$

with variance

$$\text{Var}(\hat{N}) = \frac{\hat{N}^2 \left(\frac{1}{T} - \frac{1}{\hat{N}} \right) \frac{s_f^2}{\bar{f}^2}}{\left(1 + \frac{s_f^2}{T\bar{f}^2} \right)^2}$$

Program NOREMARK

To run NOREMARK, copy the files in the subdirectory

J:\CLASSES\FW663\NOREMARK

to your local subdirectory. The main reason for doing this is to have the help files readily available to the program. Program NOREMARK is executed with the command

NOREMARK

typed at the DOS prompt. The following menu appears.

01/05/94

Memory Available = 141

10:47:57

DESIGN AND ANALYSIS OF MARK-RESIGHT EXPERIMENTS

JHE Closed Population Model Estimation
Immigration/Emigration Model Estimation
Minta-Mangel Model Estimation
Bowden's Model Estimation
Design Experiment Using Interpolation for Closed Population
JHE Closed Population Model Simulation
Immigration/Emigration Model Simulation
Minta-Mangel Estimator Simulation
Bowden's Estimator Simulation

Estimate Population Size for No Immigration/Emigration with JHE

EXIT

The ESC key takes you back one menu screen.
You can get context-sensitive help with the F1 key.

Nine options are presented for the user to select from. To select a choice the user can either specify the first letter of the choice, or use the arrow keys to move the cursor to the choice. After the cursor is positioned on the desired choice, the user hits the Enter key to execute the option. For computers with a mouse, the mouse cursor can be moved to the desired option, and double clicked to select the choice. The line "Estimate Population Size for No Immigration/Emigration with JHE" provides additional detail about each of the choices and changes as you move the cursor to different selections from the 7 choices.

The function key F1 is the help function. Context-sensitive help can be obtained any time the program is waiting for input by hitting the F1 key. A window will pop up on the screen displaying information about the program's request. To exit this window, hit the Esc key, which is equivalent to selecting the "Exit" option from the menu choices. In general, the Esc key always takes you back one window to a previous menu.

The first choice is "JHE Closed Population Model Estimation", and provides the capability to compute the JHE estimator for a set of data. Equivalent functions are provided with the next 3 options, for computing the Immigration/Emigration JHE, Minta-Mangel, and Bowden estimators. The fourth option, "Design Experiment Using Interpolation for Closed Population" allows the user

to quickly design an experiment using the simulations results from Neal (1990). These simulations were summarized in a dBase file, and this option allows the user to interpolate the simulations to provide an idea of confidence interval length for a particular set of parameter values. The next 4 choices in the main menu allow the user to simulate experiments. These options are useful in the design of experiments that require parameter values outside the ranges simulated by Neal (1990).

This introduction should be enough to get you started using Program REMARK. In general, the program is all menu driven, with additional options available via function keys. When you are being asked for input and don't understand what is being asked, try the F1 key to obtain additional information.

For your first problem, try entering the following data from the keyboard. Andrea Neal, a former graduate student at CSU, collected the following mark-resight data on mountain sheep (Neal et al. 1993). Twenty-five sheep were marked with radio collars. Fourteen resighting surveys were conducted. For each of these surveys, the following data were observed.

<u>Total Marked</u>	<u>Marks Available</u>	<u>Total Seen</u>	<u>Marked Seen</u>	<u>Unmarked Seen</u>
25	22	40	9	31
25	21	63	11	52
25	21	66	14	52
25	20	57	11	46
25	20	52	10	42
25	20	61	9	52
25	22	87	19	68
25	18	46	8	38
25	23	63	13	50
25	18	30	8	22
25	20	69	14	55
25	17	35	6	29
25	20	51	13	38
25	21	57	17	40

Run these data in Program NOREMARK with the No Immigration/Emigration Joint Hypergeometric Estimator.

To run the Bowden estimator that allows heterogeneity of resighting probabilities among individuals, you must enter the number of times each marked animal was observed, plus the total number of unmarked animals observed. The following is the number of times that each of Andrea's

25 marked sheep were seen: 10, 9, 3, 6, 7, 5, 5, 12, 2, 5, 8, 9, 8, 3, 12, 10, 4, 9, 4, 3, 6, 6, 6, 3, and 7. There were a total of 615 unmarked sheep observed. Enter these data in Program NOREMARK.

You will note that the program allows you to retrieve data with the F2 function key once the data entry screen appears. In the subdirectory

J:\CLASSES\FW663\EXERCISE.22

are a number of examples you can try, including the 2 examples you have just executed. Files with the suffix HYP are for the hypergeometric estimators (both closed and open models), whereas files with the suffix MM are for the Minta-Mangel and Bowden estimators. For the lab today, just explore the closed JHE and Bowden estimators. As shown by White (1993), the Minta-Mangel estimator does not perform properly. We will work with the open population models later.

After you understand the input for these 2 models, try exploring the design and simulation capabilities of the program. A complete user's manual formatted in Word Perfect 6.1 is provided in the file

J:\CLASSES\FW663\EXERCISE.22\USERMAN.WP.

Questions to Consider

1. How many marked sheep with 14 resighting occasions would Andrea Neal have needed to obtain a 95% confidence interval of $\pm 10\%$ for the JHE? For Bowden's estimator?
2. How many resighting occasions with 25 marked sheep would Andrea Neal have needed to obtain a 95% confidence interval of $\pm 10\%$ for the JHE? For Bowden's estimator?
3. What are the different assumptions of the JHE and Bowden's estimators? Which model seems more realistic for resighting mountain sheep from a helicopter?
4. One scenario proposed for use of mark-resight estimators is use with radio-collared bears. Resightings of bears takes place at bait stations where motion- and infrared- sensitive cameras photograph the bears. What kinds of problems would arise with such surveys?

Pertinent Literature

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