Software Review: A program for testing capture–recapture data for closure

Thomas R. Stanley and Jon D. Richards

Abstract Capture–recapture methods are widely used to estimate population parameters of free-ranging animals. Closed-population capture-recapture models, which assume there are no additions to or losses from the population over the period of study (i.e., the closure assumption), are preferred for population estimation over the open-population models, which do not assume closure, because heterogeneity in detection probabilities can be accounted for and this improves estimates. In this paper we introduce CloseTest, a new Microsoft® Windows-based program that computes the Otis et al. (1978) and Stanley and Burnham (1999) closure tests for capture–recapture data sets. Information on CloseTest features and where to obtain the program are provided.

Key words Capture–recapture, chi-square test, CloseTest, closure test, population estimation, software

Capture-recapture methods are widely used in wildlife ecology and management to study free-ranging populations of organisms. In a typical capture-recapture study, captures of individuals occur on k occasions, and unmarked individuals are marked before release and marked individuals have their marks recorded before release. The record of captures for an individual, where on the jth capture occasion ($j=1, \ldots, k$) a 1 indicates the individual was captured (0 indicates that it was not), is referred to as a capture history. Capture-recapture data, under a suitable model, can be used to estimate important parameters such as population size (Otis et al. 1978), apparent survival and the number of individuals entering the population (Cormack 1964, Jolly 1965, Seber 1965), transition probabilities between states (Hestbeck et al. 1991, Brownie et al. 1993), and covariate effects (Lebreton et al. 1992). The literature on capture-recapture theory and applications is vast (see Otis et al. 1978; Seber 1982, 1986, 1992; Pollock et al. 1990; Williams et al. 2002), and excellent software for modeling and parameter estimation is widely available (Otis et al. 1978, White et al. 1982, Burnham et al. 1987, Pradel 1989, Arnason and Schwarz 1995, White and Burnham 1999, White et al. 2001) and can often be downloaded free-of-charge over the World Wide Web (e.g., http://www.cnr.colostate.edu/~gwhite/software.html, http://www.mbr-pwrc.usgs.gov/software.html).

For population estimation using capture-recapture methods there are 2 primary classes of models in wide use. These are the closed models, in which it is assumed there are no additions to or losses from the population of interest over the period of study (i.e., the closure assumption), and the open models that allow for additions or losses over the period of study. In cases where the closure assumption can be met, the closed models are preferred over the open models because it is possible to account for realistic sources of variation in detection probabilities, such as time variation, individual heterogeneity, or behavioral variation, thereby improving population estimates (i.e., decreased

bias and increased precision). However, when the closure assumption cannot be met, it is necessary to use open models where equal catchability among individuals is assumed. Unfortunately, when the equal catchability assumption is violated (this is likely to be the case in most real-world studies), population estimates under the open models can be biased (Pollock et al. 1990).

Because of the advantages of closed models over open models for population estimation, analytical tools for detecting lack of closure in capture-recapture data sets are clearly needed. Whereas it has not been possible to construct an omnibus test for closure for capture-recapture data (Stanley and Burnham 1999), a number of partial tests have been developed. For example, Balser (1984) provided a test for temporary emigration, and Pollock et al. (1974) developed a set of 3 tests for detecting mortality or recruitment in the presence of time variation in capture probabilities. With publication of the seminal monograph by Otis et al. (1978) on closed-population capture-recapture, a test for closure developed under a null model allowing for individual heterogeneity in capture probabilities became available and was incorporated into program CAPTURE (Otis et al. 1978, White et al. 1982). More recently, Stanley and Burnham (1999), building on the work by Pollock et al. (1974), published a closure test that provides information on the nature of the closure violation. Specifically, the overall closure test they presented was decomposable into components that separately test for additions to or losses from the population. Likewise, those components can be further decomposed into subcomponents to determine which intervals between sampling occasions experienced additions or losses. In this paper we describe CloseTest, a new Windows-based software package that computes the Otis et al. (1978) and Stanley and Burnham (1999) closure tests, as well as the component and subcomponent tests for determining the nature of closure violations.

CloseTest features

Data are provided to CloseTest in the form of a capture-history matrix, where rows of the matrix represent capture histories for distinct individuals and columns represent occasions. Alternatively, CloseTest accepts a "frequency" format, in which each row represents a distinct capture history and is followed by an integer denoting how many individuals had that particular capture history. Data for occasions may be comma delimited, space delimited, or in a mixed format, and comments can be inserted into the data file. Files may be created using a spreadsheet, text editor, or some other program, but must be saved in an ASCII text format before they can be used by CloseTest.

When files are read into CloseTest, it will check the data for obvious errors, for instance incomplete capture histories or rows that are all zeros, and will report them to the user. The user can edit the data file from within CloseTest, and once it is error-free, they can analyze the data to obtain the test statistics and *P*-values for the Otis et al. (1978) and Stanley and Burnham (1999) closure tests. An example of the output (Table 1), using the *Peromyscus maniculatus* data collected by V. Reid at East Stuart Gulch, Colorado, is distributed with CloseTest as an example (i.e., Reid.dat).

The first portion of the output in Table 1 provides basic information about the data, like the path and filename, number of sampling occasions, number of distinct individuals captured (M_t+1), and the population estimate under model M_t (see Otis et al. 1978). This is followed by the test statistics and *P*-values for the Stanley and Burnham (1999) and Otis et al. (1978) closure tests. In this example the Otis et al. test does not indicate there was lack of closure, whereas the Stanley and Burnham test suggests there may have been lack of closure. Because the 2 tests were developed under different assumptions about the data, mixed results like this are not unexpected. Following the overall closure tests, the Stanley and Burnham test is decomposed into component statistics. When we examine the component statistics in Table 1 we find *P*-values for the 2 tests for additions (see the CloseTest documentation and Stanley and Burnham [1999] for details on and abbreviations for specific tests) were somewhat low (i.e., $P=0.025$ and $P=0.071$), indicating there may have been additions to the population. Furthermore, when we examine the subcomponent statistics of the NR versus JS test for additions to the population, we see there is strong evidence of additions between the second and third sampling occasions ($P=0.006$).

Results of analyses generated with CloseTest can be printed or saved to disk for later viewing from within CloseTest. CloseTest comes with extensive hypertext-linked online help and a portable document format (PDF) file of the Stanley and Burnham (1999) publication. Users can set font preferences

Table 1. CloseTest output for the *Peromyscus maniculatus* data collected by V. Reid at East Stuart Gulch, Colorado, and distributed with CloseTest as an example data set.

Data Input File = C:\Program Files\CloseTest\examples\reid.daT

N hat = 38
M_t+1 = 38
Occasions = 6
CH Data Format = List-directed input

Stanley & Burnham Closure Test (Low *P*-values suggest population not closed):

Chi-square statistic = 11.66802
df = 7
P-value = 0.11202

Otis et al. (1978) Closure Test (Low *P*-values suggest population not closed):

z-value = 0.76492
P-value = 0.77784

Component Statistics of Stanley and Burnham Closure Test

Component	Chi-square	df	*P*-value
Tests for additions to population (Low *P*-values suggest there were additions)			
NR vs JS	9.31129	3	0.02543
M_t vs NM	11.61907	6	0.07103
Tests for losses from population (Low *P*-values suggest there were losses)			
M_t vs NR	2.35673	4	0.67046
NM vs JS	0.04895	1	0.82490

Subcomponent Statistics of the NR vs. JS Test (Low *P*-values on the *j*th occasion indicates there were additions to the population between occasions *j* and *j*+1)

Occasion	Chi-square	df	*P*-value
2	7.44580	1	0.00636
3	0.04506	1	0.83190
4	1.82043	1	0.17726
5	Insufficient data for test		
2	Insufficient data for test		
3	Insufficient data for test		
4	Insufficient data for test		
5	0.04895	1	0.82490

from within the program and can specify a different text editor than the default (e.g., Microsoft Notepad). The program can be run on computers operating under Microsoft Windows 2000 or Windows XP, and the installation program is available for download free over the World Wide Web at (http://www.fort.usgs.gov/products/software/clostest/clostest.asp). Source code for the program can be obtained from the authors (J.D.R.).

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