A computer program for estimating population size by the removal method

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Resum

Un programa informàtic per a l'estimació de la grandària poblacional mitjançant el mètode *removal*

Es presenta un programa informàtic REMOVAL en llenguatge BASIC per a l'estimació de grandària poblacional mitjançant el mètode *removal* (mètode de captures successives per a poblacions tancades i esforç de mostreig constant), d'ús en un entorn VAX/VMS. El programa segueix el mètode de màxima versemblança, controlant les condicions d'error i les fórmules apropiades, i proporciona estimacions de grandària poblacional i capturabilitat, amb les corresponents desviacions típiques i els coeficients de variació, i dos estadístics de bondat d'ajustament amb els seus nivells de significació. S'utilitzen dades d'experiments *removal* per al peix ciprinodòntid *Aphanius iberus* als aiguamolls de l'Alt Empordà per a exemplificar l'ús del programa.

MOTS CLAU: Grandària poblacional, mètode *removal*, programa informàtic, entorn VAX/VMS, Cyprinodontidae, *Aphanius iberus*, aiguamolls de l'Alt Empordà.

Abstract

A BASIC computer program (REMOVAL) was developed to compute in a VAX/VMS environment all the calculations of the removal method for population size estimation (catch-effort method for closed populations with constant sampling effort). The program follows the maximum likelihood methodology, checks the failure conditions, applies the appropriate formula, and displays the estimates of population size and catchability, with their standard deviations and coefficients of variation, and two goodness-of-fit statistics with their significance levels. Data of removal experiments for the cyprinodontid fish *Aphanius iberus* in the Alt Empordà wetlands are used to exemplify the use of the program.

KEYWORDS: Population size, removal method, computer program, VAX/VMS software, Cyprinodontidae, *Aphanius iberus*, Alt Empordà wetlands.

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Introduction

Catch-effort methods to estimate population size are based on the general assumption that the size of a sample caught from a population is proportional to the effort put into taking the sample (SEBER, 1982, 1986). More specifically this means that one unit of sampling effort is assumed to catch a fixed proportion of the population so that if samples are permanently removed, the decline in population size will produce a decline in catch-per-unit effort.

The removal method is a catch-effort method for closed populations when constant sampling effort is applied. It is the most widely used method to estimate the population size of fish in streams or the littoral zone of lakes when using electrofishing (BOHLIN *et al.*, 1989; LOBÓN-CERVIÁ, 1991), and is also often applied to small mammals (MARGALEF, 1974; SEBER, 1982).

The basic assumptions of this method are:

(I) the population is closed during the experiment, i.e. there is no migration, birth or natural mortality,

(II) the probability of capture in a sample is the same fop each individual exposed to capture, and

(III) the probability of capture p remains constant from sample to sample.

The first assumption is easily assured by closing the sampling area (GATZ & LOAR, 1988) and concentrating the experiment for as short a period of time as possible (SEBER, 1982). The other assumptions are more problematic (MAHON, 1980; SCHNUTE, 1983; BOHLIN *et al.*, 1989) and typically verified with goodness-of-fit statistics (ZIPPIN, 1956). The usual violation of the second assumption (e.g. because of dependence of catchability on individual size) can be avoided identifying subsets of the population that are equally catchable and making separate population estimates for each subset (GATZ & LOAR, 1988). Furthermore, a relatively large proportion of the population must be captured in order to obtain reasonably accurate estimates (SEBER, 1982; BOHLIN *et al.*, 1990).

TABLE I: Population-size statistics computed by REMOVAL program. All symbols according to SEBER (1982).

Estadístics de grandària poblacional calculats pel programa REMOVAL. Tots els símbols segons **SEBER (1982).**

Symbol	*Statistic*
$\hat{N}$	Estimate of population size
$\hat{\sigma}[\hat{N}]$	Standard deviation of $\hat{N}$
$\hat{C}[\hat{N}]$	Coefficient of variation of $\hat{N}$
$\hat{p}$	Estimate of the probability of capture
$\hat{\sigma}[\hat{p}]$	Standard deviation of $\hat{p}$
$\hat{C}[\hat{p}]$	Coefficient of variation of $\hat{p}$
N^*	Estimate of population size, adjusted for bias in the two-sample method
p^*	Estimate of the probability of capture, adjusted for bias in the two-sample method
T_1	Goodness-of-fit statistic
sign.	Significance of T_1, at the 5%, 1% or 0.1% levels
T_2	Goodness-of-fit statistic
sign.	Significance of T_2, at the 5%, 1% or 0.1% levels

A VAX BASIC 3.2 computer program (REMOVAL) was developed to compute in a VAX/VMS environment all the calculations of the removal method by maximum likelihood. The program was used successfully on a population dynamics study of the cyprinodontid fish *Aphanius iberus* (Cuvier & Valenciennes) i the Alt Empordà wetlands (GARCÍA-BERTHOU, 1990), and is available free of charge from the author. The conversion of the program to other operating systems may be easy and a MS-DOS version is in preparation.

Although the program only uses the maximum likelihood methods, we must point out that several other alternative methodologies, not considered herein, have been recently proposed (see e.g. OTIS *et al.*, 1978; SEBER 1982; SCHNUTE, 1983; ROUTLEDGE, 1989).

Program description

The program follows the maximum-likelihood methodology (MORAN, 1951; ZIPPIN, 1956, 1958) reviewed by SEBER (1982), though recommendations of some other authors were considered and are detailed herein. All symbols in this paper (for meaning see Tables I and II) follow SEBER (1982).

The conditions for failure check if the experiment fails. The general condition for failure is (SEBER & WHALE, 1970).

$$\sum_{i=1}^{s} (s + 1 - 2i)n_i < 0 \qquad (1.)$$

where n_i is the size of the ith sample removed from the population, and s is the total number of removed samples.

Additionally, for the three-sample method (i.e., $s = 3$), the program also checks the two following failure cases

$$X = Y \text{ and } Y^2 + 6\,XY - 3\,X^2 < 0$$

where usually $X = 2n_1 + n_2$ and $Y = n_1 + n_2 + n_3$.

We must note that when $n_1 = n_3$ or $\hat{p} = 1$, then alternatively $X = 2n_1 + n_2$ but $Y = 2n_1 - n_3$ as suggested by LELEK (1974) and not considered by SEBER (1982).

Finally, for the two-sample method (i.e., $s = 2$), the program also checks the condition for failure $n_1 = n_2$ and the rough acceptance guide

$$\hat{N}\hat{p}^3 - 16\,(1 - \hat{p})^2(2 - \hat{p}) < 0.$$

Another difference referred to the methodology reviewed by SEBER (1982) relates to the estimate of the probability of capture ($\hat{p}$). According to BOHLIN *et al.* (1989) $\hat{p}$ is not estimated by the Zippin's graphs (as proposed by SEBER, 1982) but by iterative solution using

$$\frac{n_1 \sum_{i=1}^{s} n_i}{\sum_{i=1}^{s} (i - 1)\, n_i}$$

as a first guess of $\hat{p}$. When the total catch is less than 3 we use 0.01 as a first guess of $\hat{p}$ to avoid computation errors.

The results of the computation are summarized interactively on the screen and if convenient the complete results (Table II) are sent to a file to be printed. The coefficient of variation is displayed to illustrate the precision of the estimates. N^* and p^* are the estimates adjusted for bias in the two-sample method. The two alternative goodness-of-fit statistics T_1 and T_2 (ZIPPIN, 1956) are computed to test the validity of the model, and their statistical significance at the 5%, 1% or 0.1% levels are provided. The condition for failure (if any) and method of calculation for each experiment are also specified in the results.

Case example

Data of the removal experiments for the cyprinodontid fish *Aphanius iberus* in the Alt Empordà wetlands (GARCÍA-BERTHOU, 1990, see GARCÍA-BERTHOU & MORENO-AMICH, 1992 for published ecological data on this study population), are used to exemplify the program output (Table II).

The first example (June 0+ group) shows a three-sample experiment, and was successful according to the goodness-of-fit statistic ($P > 0.05$). The three samples contained 19, 13 and 5 individuals respectively, and produced an estimate of the population size

TABLE II: Program output example for *Aphanius iberus* removal experiments in the Alt Empordà wetlands. n_i = size of the ith sample removed from the population, *** = $P < 0.001$, n.s. = not significant ($P > 0.05$). All other symbols according to Table I. Method code: 2 = method of MORAN (1951) and ZIPPIN (1956, 1958) adapted for 3 samples by JUNGÉ & LIBOSVÁRSKÝ (1965), 3 = method of MORAN (1951) and ZIPPIN (1956, 1958), 6 = experiment failure according to SEBER & WHALE (1970).

Exemple de sortida del programa per als experiments *removal* amb *Aphanius iberus* als Aiguamolls de l'Alt Empordà. n_i = grandària de la mostra *i* extreta de la població, *** = $P < 0{,}001$, n.s. = no significatiu ($P > 0{,}05$). Tots els altres símbols seguint la taula I. Codi del mètode: 2 = mètode de MORAN (1951) i ZIPPIN (1956, 1958) adaptat per a 3 mostres per JUNGÉ & LIBOSVÁRSKÝ (1965), 3 = mètode de MORAN (1951) i ZIPPIN (1956, 1958), 6 = fallada de l'experiment d'acord amb SEBER & WHALE (1970).

Population	n_i	$\hat{N}$ $\hat{\sigma}[\hat{N}]$ $\hat{C}[N]$ N^*	$\hat{p}$ $\hat{\sigma}[\hat{p}]$ $\hat{C}[\hat{p}]$ p^*	T_1 T_2	sign.	Method
June 0+ group	19	44.30	0.452	0.60	n.s.	2
	13	6.47	0.118	0.59	n.s.	
	5	0.146	0.267			
		-	-			
August 0+ group	142	293.1	0.429	26.9	***	3
	38	10.54	0.045	27.9	***	
	60	0.036	0.083			
	22	-	-			
October 0+ group	13	50.10	0.225	3.87	n.s.	3
	8	19.17	0.127	3.84	n.s.	
	3	0.383	0.560			
	8	-	-			
January 0+ group	18	-	-	-	-	3, 6
	28	-	-	-	-	
	23	-	-			
	20	-	-			

of 44.30 (standard deviation = 6.47, coefficient of variation = 0.146) and an estimate of the probability of capture of 0.452 (standard deviation = 0.118, coefficient of variation = 0.267).

Likewise, data for the October 0+ group, with 4 samples (general method) also fit the model ($P > 0.05$). On the other hand, January 0+ group data shows an experiment that failed according to the failure condition (1.), and the population size cannot be estimated. Finally, August 0+ group data did not fit the model either ($P < 0.001$), and therefore the estimate of population size should not be considered.

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