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Evaluating catchability assumptions for change-in-ratio and index-removal estimators, with application to southern rock lobster

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Abstract

Change-in-ratio (CIR) and index-removal (IR) methods can be used to estimate exploitation rate when a survey is conducted before and after a harvest. When the magnitude of the harvest is also known, it is possible to estimate the abundance and the survey catchability coefficient. We present three diagnostic procedures for evaluating whether the assumptions of constant catchability appear reasonable. We show for the CIR method that it is not necessary to assume the two defined groups (generally, legal, and sublegal size animals) have equal catchability: if sublegal size animals are unexploited the estimated exploitation rate for the legal size group is unbiased. The assumption for the CIR method that the ratio of survey catchabilities of the two size groups does not vary over time can be evaluated by comparing the size composition of sublegal size animals over time in the surveys. For the IR method, the assumption that survey catchability remains constant over time can be evaluated by comparing the catch rates of sublegal sized animals before and after the fishing season. The assumption that all animals have the same catchability at a point in time, necessary for the IR method, can be evaluated by estimating the population separately by size group and comparing the sum of the population estimates with the estimate of the total population computed from all of the data; this requires that the harvest be known by size group. Data from the southern rock lobster fishery in Tasmania are used to illustrate these techniques.

Keywords: Change-in-ratio; Index-removal; Lobsters; Diagnostics

1. Introduction

Biomass and fishing mortality estimates are commonly used as performance indicators in fishery management. Various authors have suggested using change-in-ratio (CIR) and index-removal (IR) methods, which provide estimates of exploitation rate and, possibly, of population size and survey catchability coefficient (Chapman, 1961; Paulik and Robson, 1969; Ricker, 1975; Pollock and Hoenig, 1998; Hoenig and Pollock, 1998). Although these methods have been used in the assessment of various lobster and crab species, it is surprising that they have not been used more (Dawe et al., 1993; Chen et al., 1998; Frusher et al., 1997, 1998; Claytor and Allard, 2003). Both methods require surveys be conducted before and after a period of harvest. The methods differ only in the way the survey data are interpreted.

We propose a series of simple diagnostic procedures that can be applied to the data to determine the appropriateness of the assumptions of the constancy of catchability. We illustrate the use of the diagnostic methods with data obtained from a fisheries-independent study of the Tasmanian rock lobster (*Jasus edwardsii*) fishery in which pre-season and post-season surveys were conducted from 1992 to 1998.

2. The IR and CIR methods

2.1. Index-removal

The IR estimator of exploitation rate (U_{IR}) is

$$\hat{U}_{\mathrm{IR}} = \frac{c_1 - c_2}{c_1} \quad (1)$$

where c_1 and c_2 are the catch rates of legal sized animals in the pre-season and post-season surveys, respectively, and the ˆ symbol indicates an estimate.

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Exploitation rate can also be expressed as:

$$U = \frac{R}{N} \tag{2}$$

where R is the number of animals removed by the fishery and N is the abundance before the harvest. Therefore, abundance can be estimated as:

$$\hat{N} = \frac{Rc_1}{c_1 - c_2} \tag{3}$$

where R, c_1 and c_2 are as described above.

Hoenig and Pollock (1998) listed the assumptions for the IR method: (1) the population is closed between surveys except for harvest and thus there is no net change to the population through immigration, emigration or recruitment (in crustaceans this is equivalent to molting), (2) all animals are equally catchable, and (3) catchability does not change from one survey to the next.

2.2. Change-in-ratio

The CIR method is based on changes in the ratio of abundance of two or more components of the population over time (Kelker, 1940; Pollock and Hoenig, 1998). Applications involving estimation of population size are found primarily in the wildlife literature, although recently it has been used in fisheries studies by Chen et al. (1998), Dawe et al. (1993), Frusher et al. (1997, 1998), and Claytor and Allard (2003). Typically, the two components are defined to be legal-size, fully recruited animals and a sublegal size class. Paulik and Robson (1969) derived a CIR estimator of exploitation rate but there has been limited attention given to this approach. The CIR estimator of exploitation rate (U_{CIR}) of the legal sized component when the sublegal component of the fishery is unharvested is:

$$\hat{U}_{\text{CIR}} = \frac{p_1 - p_2}{p_1(1 - p_2)} \tag{4}$$

where p_i is the proportion of legal sized animals in the catch in the ith survey. The population size of legal-size animals before the harvest can be estimated if the harvest R of legal size animals is known and the harvest of sublegal sized animals is zero. Thus,

$$\hat{N} = \frac{R(1 - p_2)}{p_1 - p_2}. \tag{5}$$

The assumptions in general are: (1) the population is closed except for the removal and (2) all animals are equally catchable. We show (Appendix A) that, if only one of the components is harvested and the two components of the population have a constant ratio of catchability over time, then the estimate of exploitation rate (for the exploited component) will be unbiased. That is, for the special case where one component is not harvested, it is not necessary to assume equal catchability of the two components. However, for any change in the ratio of catchabilities over time, the bias is greater the lower the exploitation rate (Appendix A). Previously, it was established that the estimate of abundance of legal-size animals would be unbiased if only legal-size animals are harvested and the ratio of catchabilities of legal and sublegal size animals remains constant over time (see Seber, 1982).

3. Evaluating the assumptions—IR method

3.1. Catchability varying by time

In most lobster fisheries there is a mandatory minimum size limit. If there is no illegal harvest of sublegal animals, and if the above assumptions hold, then lobsters below this limit would be expected to have the same catch rate in the two surveys. If comparison of the survey catch rates of the sublegal components over time indicates this is not the case, then the validity of the IR method is called into question. There are several ways to examine this question. To begin, the catch data for each survey can be tabulated by size class and converted to size-specific catch rates (catch per haul of the fishing gear). Animals just below the legal size limit should be similar to legal sized animals in terms of behavior and catchability. Thus, if the catch rate of animals just below the legal size limit hasn't changed from one survey to the next, then it is reasonable to suppose the catchability of legal sized animals has not changed. It may be informative to plot the catch rates from each survey against the size class to look for systematic differences between the surveys. The number of size classes will depend on the sample sizes—more size classes provide a more detailed look at the data but result in smaller samples and thus in higher variability in the catches. If a formal test is desired of whether the catch rates have changed from one survey to the next, it can be obtained using a t-test for the size class immediately below the legal size limit or using Hotelling's T^2 test (see Morrison, 1990) to test equality of catch rates over time for several size classes simultaneously.

An alternative to looking for changes in catch rates is to plot the proportional change in catch rate from one survey to the next versus size class. Proportional change in catch rate is equivalent to a calculation of exploitation rate, i.e., the proportional change is given by Eq. (1). Sublegal size animals are not harvested; consequently, the estimates from Eq. (1) should average out to close to zero.

It is generally preferable to use the same set of stations for both surveys, rather than randomizing each survey separately, in order to achieve greater precision (Chen et al., 1998). In this case, the test of whether sublegal catch rates have changed over time can be accomplished by using a paired t-test or the one-sample Hotelling's T^2 test (see Morrison, 1990).

A formal statistical test is just one tool for assessing the assumption of constant catchability. It should not be used as the sole criterion for two reasons. First, with large sample sizes, it is possible to detect real but trivial changes in catch rates. A trivial change in catch rates is likely to produce only a trivial bias in parameter estimates. This can be explored using a sensitivity analysis. For example, if the catch rate of sublegal sized animals in the second survey is 85% of the catch rate in the first survey, then the catch rate of legal-sized animals might have declined by a similar amount due to changing catchability. Hence, the catch rate of legal-sized animals in the second survey could be divided by 0.85 and the exploitation rate or population size can be recalculated with the new value. (This is suggested as a sensitivity analysis and not as an estimation procedure.) Second, the nature of the change in catchability is as important as the magnitude