Appendix A

Appendix A1.–Detection and mitigation of selective sampling during a two-event mark recapture experiment.

Size- and sex-selective sampling may cause bias in two-event mark-recapture estimates of abundance and size and sex composition. Kolmogorov-Smirnov (KS) two sample tests are used to detect size-selective sampling and contingency table analyses (Chi-square tests of independence) are used to detect evidence of sex-selective sampling.

Results of the KS and Chi-square tests will dictate whether the data needs to be stratified to obtain an unbiased estimate of abundance. The nature of the detected selectivity will also determine whether the first, second, or both event samples are used for estimating size and sex compositions.

## Definitions

M = Lengths or sex of fish marked in the first event

C = Lengths or sex of fish inspected for marks in the second event

R = Lengths or sex of fish marked in the first event and recaptured in the second event

## Size-Selective Sampling: KS Tests

Three KS tests are used to test for size-selective sampling.

|  |  |  |
| --- | --- | --- |
| KSTest 1 | C vs R | Used to detect size selectivity during the 1st sampling event.  Ho: Length distributions of populations associated with C and R are equal |
| KSTest 2 | M vs R | Used to detect size selectivity during the 2nd sampling event.  Ho: Length distributions of populations associated with M and R are equal |
| KSTest 3 | M vs C | Used to corroborate the results of the first two tests.  Ho: Length distributions of populations associated with M and C are equal |

## Sex-Selective Sampling: Chi-Square Tests

Three contingency table analyses (χ2-tests on 2x2 tables) are used to test for sex-selective sampling.

|  |  |  |
| --- | --- | --- |
| χ2 Test 1 | C vs R | Used to detect sex selectivity during the 1st sampling event.  Ho: Sex is independent of the C - R classification |
| χ2 Test 2 | M vs R | Used to detect sex selectivity during the 2nd sampling event.  Ho: Sex is independent of the M - R classification |
| χ2 Test 3 | M vs C | Used to corroborate the results of the first two tests.  Ho: Sex is independent of the M - C classification |

Table A1 presents possible results of selectivity testing, their interpretation, and prescribed action.

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Table A1.–Possible results of selectivity testing, interpretation and action.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | KS or χ2 Test | | |  |
| Case | M vs. R  (2nd event test) | C vs. R (1st event test) | M vs. C (1st vs 2nd event) | Interpretation and Action |
| I | Fail to reject Ho | Fail to reject Ho | Fail to reject Ho | **Interpretation**: No selectivity during either sampling event.  **Action**:  Abundance: Use a Petersen-type model without stratification.  Composition: Use all data from both sampling events. |
| II | Reject Ho | Fail to reject Ho | Reject Ho | **Interpretation:** No selectivity during the 1st event but there is selectivity during the 2nd event.  **Action**:  Abundance: Use a Petersen-type model without stratification.  Composition: Use data from the 1st sampling event without stratification. 2nd event data only used if stratification of the abundance estimate is performed, with weighting according to Equations 1-3 below. |
| III | Fail to reject Ho | Reject Ho | Reject Ho | **Interpretation:** No selectivity during the 2nd  event but there is selectivity during the 1st event.  **Action**:  Abundance: Use a Petersen-type model without stratification.  Composition: Use data from the 2nd sampling event without stratification. 1st event data may be incorporated into composition estimation only after stratification of the abundance estimate and appropriate weighting according to Equations 1-3 below. |
| IV | Reject Ho | Reject Ho | Either result | **Interpretation:** Selectivity during both 1st and 2nd events.  **Action**:  Abundance: Use a stratified Petersen-type model, with estimates calculated separately for each stratum. Sum stratum estimates for overall abundance.  Composition: Combine stratum estimates according to Equations 1-3 below. |
| V | Fail to reject Ho | Fail to reject Ho | Reject Ho | **Interpretation:** The results of the 3 tests are inconsistent.  **Action:** Need to determine which of Cases I-IV best fits the data. Inconsistency can arise from high power of the M vs. C test or low power of the tests involving R. Examine sample sizes (generally M or C from <100 fish and R from <30 are considered small), magnitude of the test statistics (Dmax), and the *P*-values of the three tests to determine which of which of Cases I-IV best fits the data. |

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## Composition estimation for stratified estimates

An estimate of the proportion of the population in the *kth*size or sex category for stratified data with *I* strata is calculated as follows:

, (1)

with variance estimated as

, (2)

where

|  |  |
| --- | --- |
| = | estimated proportion of fish belonging to category *k* in stratum *i*; |
| = | estimated abundance in stratum *i*; and |
| = | estimated total abundance |
|  | =. (3) |

Appendix A2.–Tests of consistency for the Petersen estimator (from Seber 1982, page 438).

## Tests of Consistency for Petersen Estimator

Three contingency table analyses are used to determine if the Petersen estimate can be used (Seber 1982). If any of the null hypotheses are not rejected, then a Petersen estimator may be used. If all three of the null hypotheses are rejected, a temporally or spatially-stratified estimator (Darroch 1961) should be used to estimate abundance.

Seber (1982) describes 4 conditions that lead to an unbiased Petersen estimate, some of which can be tested directly:

1. Marked fish mix completely with unmarked fish between events.
2. Equal probability of capture in event 1 and equal movement patterns of marked and unmarked fish.
3. Equal probability of capture in event 2
4. The expected number of marked fish in recapture strata is proportional to the number of unmarked fish.

In the following tables, the terminology of Seber (1982) is followed, where *a*represents fish marked in the first event, *n* fish captured in second event and *m* marked fish recaptured; *m•j* and *mi•* represent summation over the *ith* and *jth* indices, respectively.

1. **Mixing Test**

Tests the hypothesis (condition 1) that movement probabilities (θ*ij*), describing the probability that a fish moves from marking stratum *i* to recapture stratum *j*, are independent of marking stratum: H0: θ*ij* = θ*j* for all *i* and *j*.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Area/Time Marking Strata *(i)* | Area/Time Recapture Strata *(j)* | | | | Not Recaptured *ai – mi•* |
| 1 | 2 | … | t |
| 1 | *m11* | *m12* | *…* | *m1t* | *a1 – m1•* |
| 2 | *m21* | *m22* | *…* | *m2t* | *a2 – m2•* |
| *…* | *…* | *…* | *…* | *…* | … |
| s | *ms1* | *ms2* | *…* | *mst* | *as – ms•* |

1. **Equal Proportions Testa (SPASb terminology)**

Tests the hypothesis (condition 4) that the marked to unmarked ratio among recapture strata is constant: H0: Σ*ai*θ*ij /Uj* = *k,* where *k* = a constant, *Uj* = unmarked fish in stratum *j* at the time of 2nd event sampling, and *ai* = number of marked fish released in stratum *i*. Failure to reject H0 means the Petersen estimator should be used only if the degree of closure among tagging strata is constant, i.e. Σ*j*θ*ij* = λ (Schwarz and Taylor 1998; p 289). A special case of closure is when all recapture strata are sampled, such as in a fishwheel to fishwheel experiment, where Σ*j*θ*ij* = 1.0; otherwise biological and experimental design information should be used to assess the degree of closure.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | Area/Time Recapture Strata *(j)* | | | |
|  | 1 | 2 | … | t |
| Recaptured (*m.j*) | *m•1* | *m•2* | … | *m•t* |
| Unmarked (*nj - m.j*) | *n1 - m•1* | *n2 - m•2* | … | *nt - m•t* |

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1. **Complete Mixing Testa (SPASb terminology)**

Tests the hypothesis that the probability of re-sighting a released animal is independent of its stratum of origin: H0: *Σjθijpj = d*, where *pj* is the probability of capturing a fish in recapture stratum *j* during the second event, and *d* is a constant.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | Area/Time Marking Strata *(i)* | | | |
|  | 1 | 2 | … | s |
| Recaptured (*mi*) | *m1•* | *m2•* | … | *ms•* |
| Not Recaptured (*ai - mi•*) | *a1 - m1•* | *a2 - m2•* | … | *as - ms•* |

a There is no 1:1 correspondence between Tests II and III and conditions 2-3 above. It is pointed out that equal probability of capture in event 1 will lead to (expected) non-significant Test II results, as will mixing, and that equal probability of capture in event 2 along with equal closure (Σjθij = λ) will also lead to (expected) non-significant Test III results.

b Stratified Population Analysis System (Arnason, A.N., C.W. Kirby,C.J. Schwarz and J.R. Irvine. 1996. Computer Analysis of Data from Stratified Mark-Recovery Experiments for Estimation of Salmon Escapements and Other Populations, Canadian Technical Report of Fisheries and Aquatic Sciences 2106.