A Likelihood Model for Incorporating Tag Loss Into the Inference of Abundance from Mark-Recapture Data

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Introduction

- Spawning abundance (escapement) of anadromous fish populations is a metric of critical importance
  - to monitor population trends
  - to determine if escapement goals of fisheries management programs are being met
- Direct and indirect methods to estimate abundance:
  - counts - fish ladders, weirs/traps, sonars, counting towers, etc. (total count, or sample + expansion)
  - redd counts (walking or aerial) + expansion
  - mark-recapture

Mark-Recapture - Petersen estimators:

$$\hat{N} = \frac{(M+1)(C+1)}{(R+1)} - 1$$

$$\hat{Var}(\hat{N}) = \frac{(M+1)(C+1)(M-R)(C-R)}{(R+1)^2(R+2)}$$

$\hat{N}$ = abundance estimate

M = number of tagged/marked fish

C = number of captured fish

R = number of (re)captured fish with a tag/mark

Seber, G. A. F. 1973. The estimation of animal abundance and related parameters. Griffin, London, Great Britain.

Mark-Recapture - Petersen estimators:

- **Assumptions:**
  - population is closed (no recruitment)
  - tagging and recapture are non-overlapping events
  - random sampling (equal probability) for tagging, and for (re)capture
  - tagging does not affect survival nor catchability
  - tags are not lost prior to recapture
- **Conditions generally applicable for estimation of spawning escapement - fish can be sampled and marked during migration, and recaptured (resighted) during spawning ground surveys**
- **EXCEPT tag loss.**

Tag Loss

- A commonly used tag is plastic T-bar anchor tag (e.g., Floy tag)

- Field studies show that tag loss can be substantial among salmonids

$$\hat{N} = \frac{(M+1)(C+1)}{(R+1)} - 1$$

- And, if tags are lost:
  - the value of M will be greater than the actual number of marked fish susceptible of being recaptured (M^{actual})
  - and, the $\hat{N}$ will be biased upwards

- Therefore, need to estimate rate of tag loss (q) and correct M to eliminate the bias

How to Estimate Rate of Tag Loss (q)?

- **Perform Mark-Recapture study with double-tagged fish**
  - **Estimate tag loss based on the proportion of fish which retain both (D_2) or only one tag (D_1)**
  - **Double-tagging can be conducted as part of a single tagging mark-recapture study, or separately (using similar tags, under similar conditions)**

- **Alternative double-tagging designs:**
  - **<u>Case 1</u>: one non-permanent tag and one permanent tag or mark (e.g., fin clip, opercule punch)**
  - **<u>Case 2</u>: both tags are non-permanent (typically, two of the same tag type)**

Double-Tagging to Estimate Tag Loss (q)

If Case 1 (2nd tag is permanent):

$$\hat{q} = \frac{D_1}{D_2 + D_1}$$

If Case 2 (2 identical non-permanent tags):

$$\hat{q} = \frac{D_1}{2D_2 + D_1}$$

Gulland, J.A. 1963. On the analysis of double-tagging experiments. Int. Comm. Northwest Atl. Fish. Spec. Publ. 4: 228-229.

Then, use q to correct for tag loss:

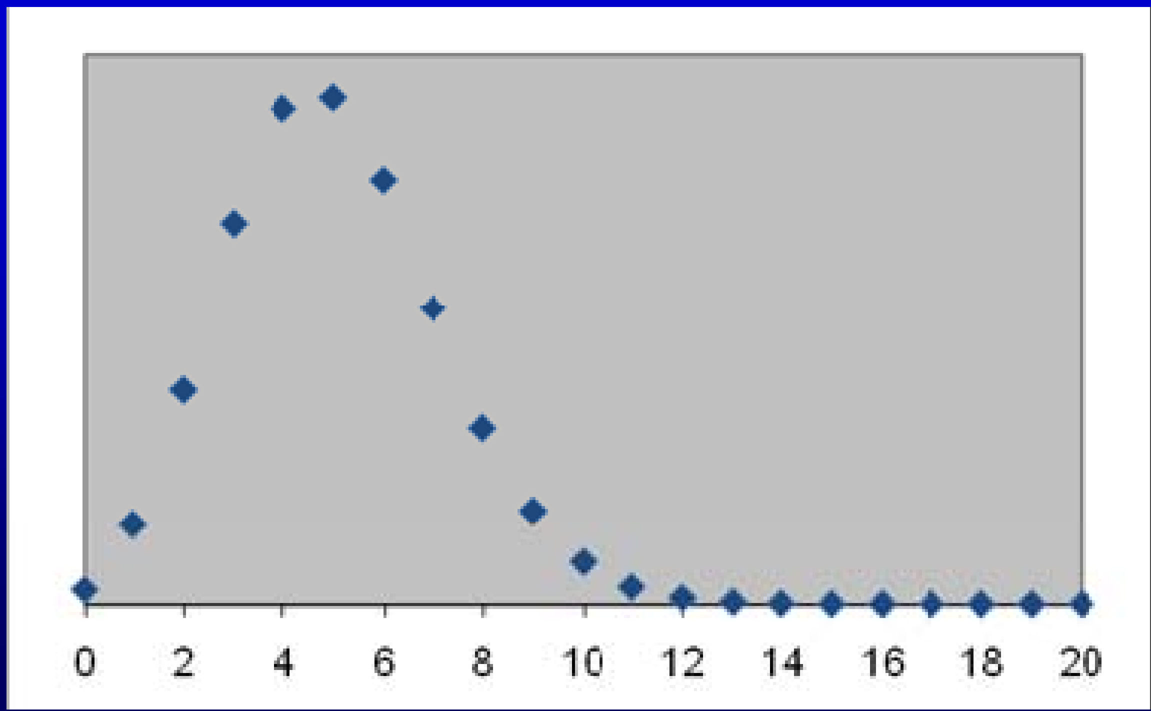
$$M^{actual} = M \times (1 - q)$$

Variance of $\hat{q}$

- **HOWEVER, this correction of M does not incorporate the uncertainty of $\hat{q}$**

- **For a given rate of tag loss, D_1 is a discrete random variable with a binomial probability distribution (e.g., Case 1 where q = 10%, and $D = D_2 + D_1 = 50$)**

$P(D_1 \mid q)$:

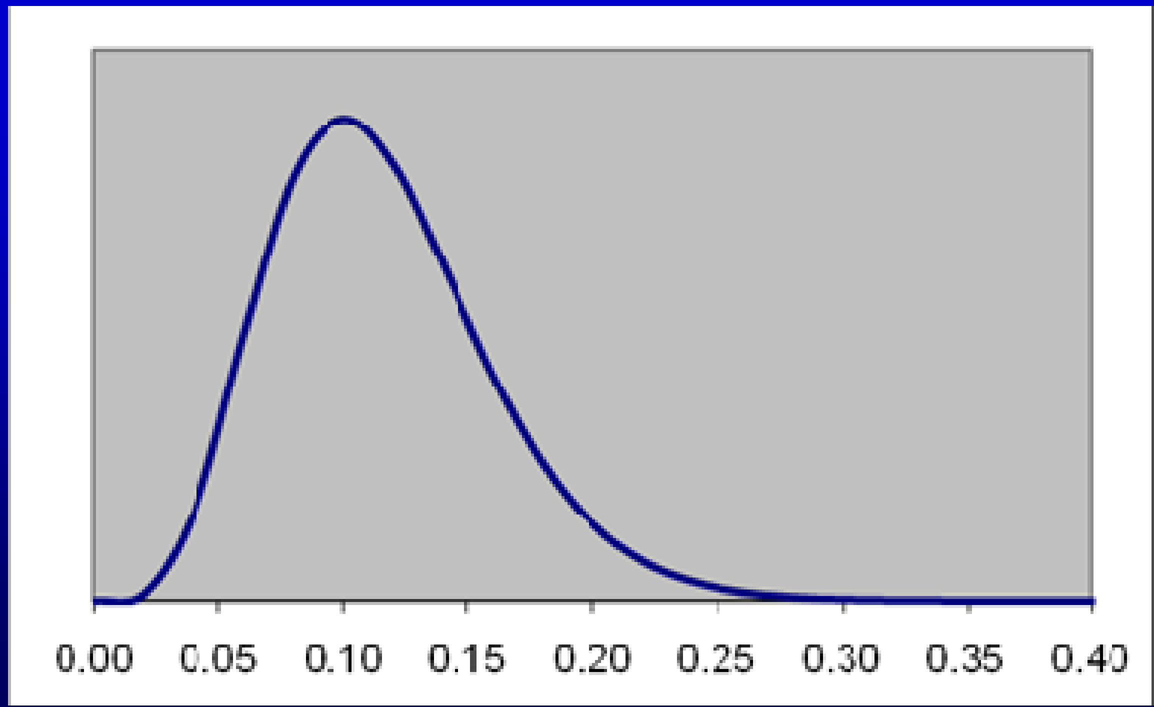


Likelihood Distribution of q

• Similarly, for a given set of observed values for D_1 and D_2 (as obtained in a mark-recapture study), tag loss (q) is a continuous parameter with a binomial likelihood function

(e.g., Case 1 where $D_1 = 5$ and $D_2 = 45$, $D = 50$)

$L(q \mid D_1)$:

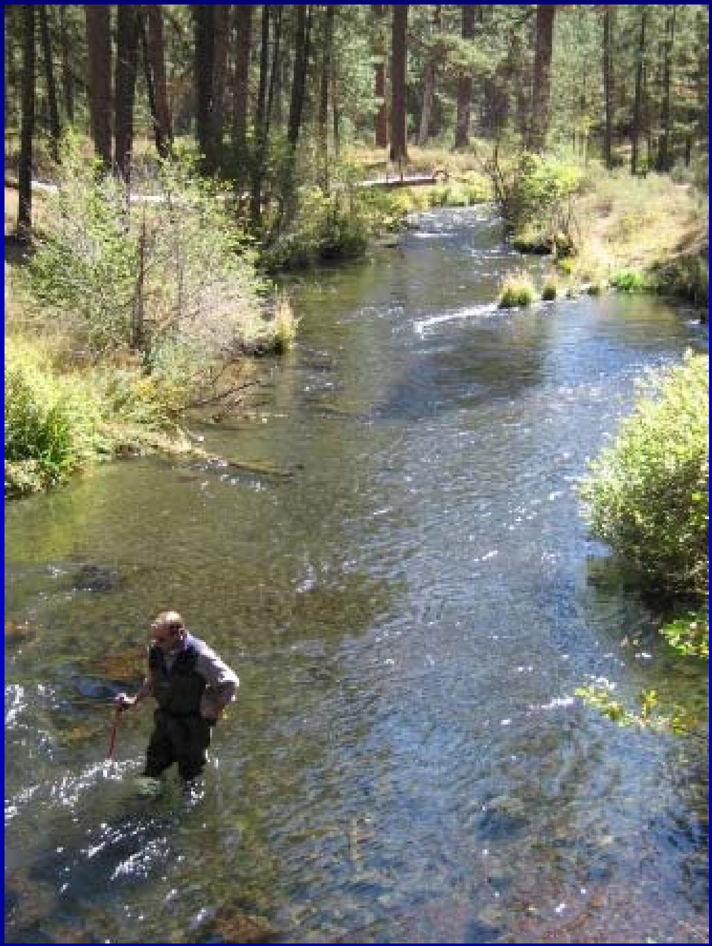


Metolius River Kokanee

- We participated with CTWSRO, ODFW and PGE in a 2007 mark-recapture study of Lake Billy Chinook kokanee

- Correction for tag loss in previous studies assumed to be 25% (Smith et al. 1978 – Rogue River spring Chinook)

- The 2007 study included double-tagging using Floy tags of alternative colors (Case 2), to obtain a Metolius kokanee-specific estimate of q


2007 Kokanee Mark-Recapture Study

Double-tag	Single-tag	Total
$M_D = 491$	$M_S = 2{,}807$	$M = 3{,}298$
$D_1 = 21$	$S = 218$	$R = 277$
$D_2 = 30$		$C = 11{,}444$

Case 2: $$\hat{q} = \frac{D_1}{2D_2 + D_1} = \frac{21}{2(30) + 21} = 26\%$$

But, how to calculate uncertainty of $\hat{q}$?

And, how to incorporate this uncertainty into the Petersen estimation for abundance ($\hat{N}$)?

Binomial-Hypergeometric Likelihood Model

We developed a formal though simple model to incorporate tag loss rate and its uncertainty into a calculation of population abundance – provides a realistic estimate of abundance and its uncertainty

Two-step model framework:

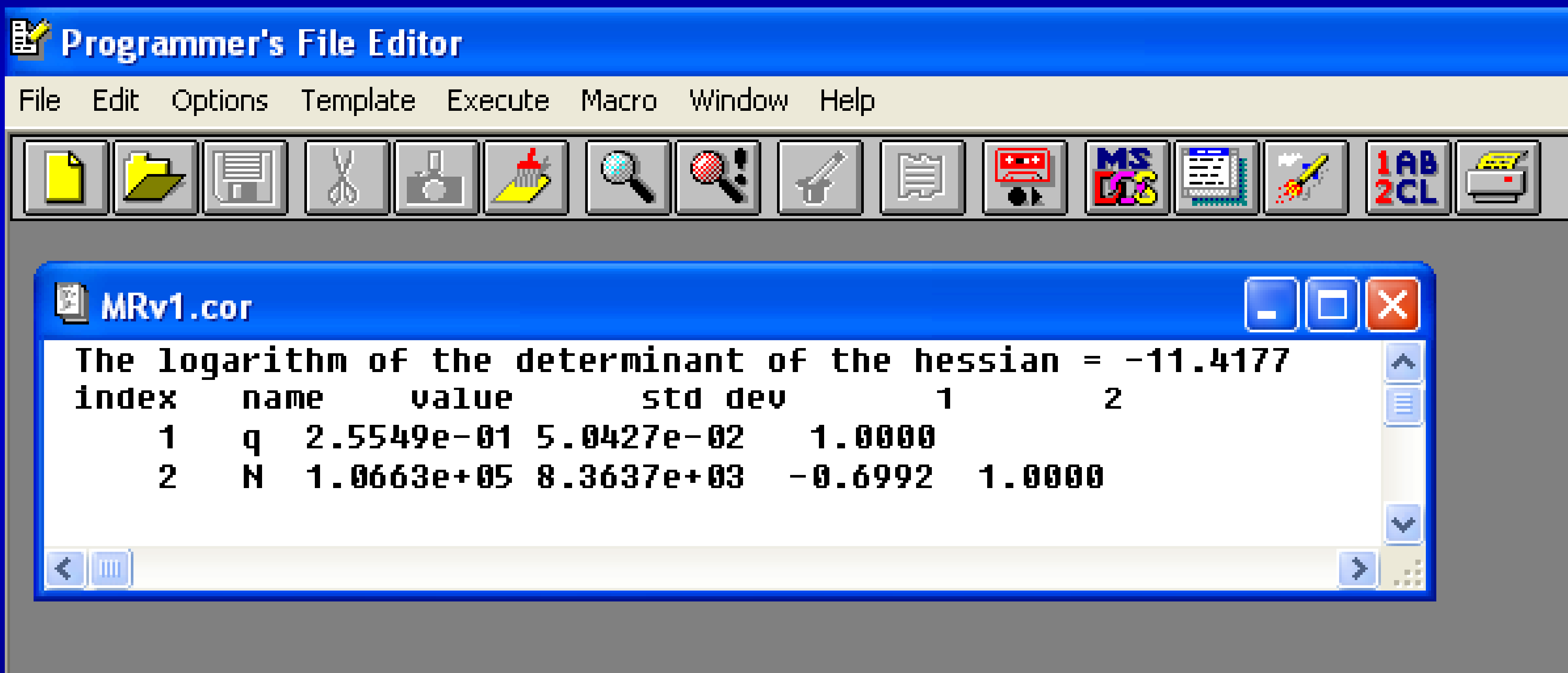
1. binomial likelihood model to estimate rate of tag loss (q) and uncertainty – S.E.(q)
2. hypergeometric likelihood model to estimate abundance (N) and overall uncertainty – S.E.(N)

Binomial-Hypergeometric Likelihood Model
Data Input File

MRdata.txt *

```
#Binomial-Hypergeometric Likelihood Model
#
# Part1.  Double-Tagging Recapture data for estimating tag loss rate
#
#D1: number of recaptured double-tagged fish retaining one tag
21
#
#D2: number of recaptured double-tagged fish retaining two tags
30
#
#
# Part 2.  Mark-Recapture data for single-tagged and double-tagged fish, used for estimating abundance
#
#M(S): number of fish initially single-tagged and released
2807
#
#M(D): number of fish initially double-tagged and released
491
#
#C: total number of (re)captured fish (includes tagged and untagged fish)
11444
#
#R: total number of recaptured fish with tag(s) - single-tagged + double-tagged fish
277
```

Binomial-Hypergeometric Likelihood Model
Data Output File

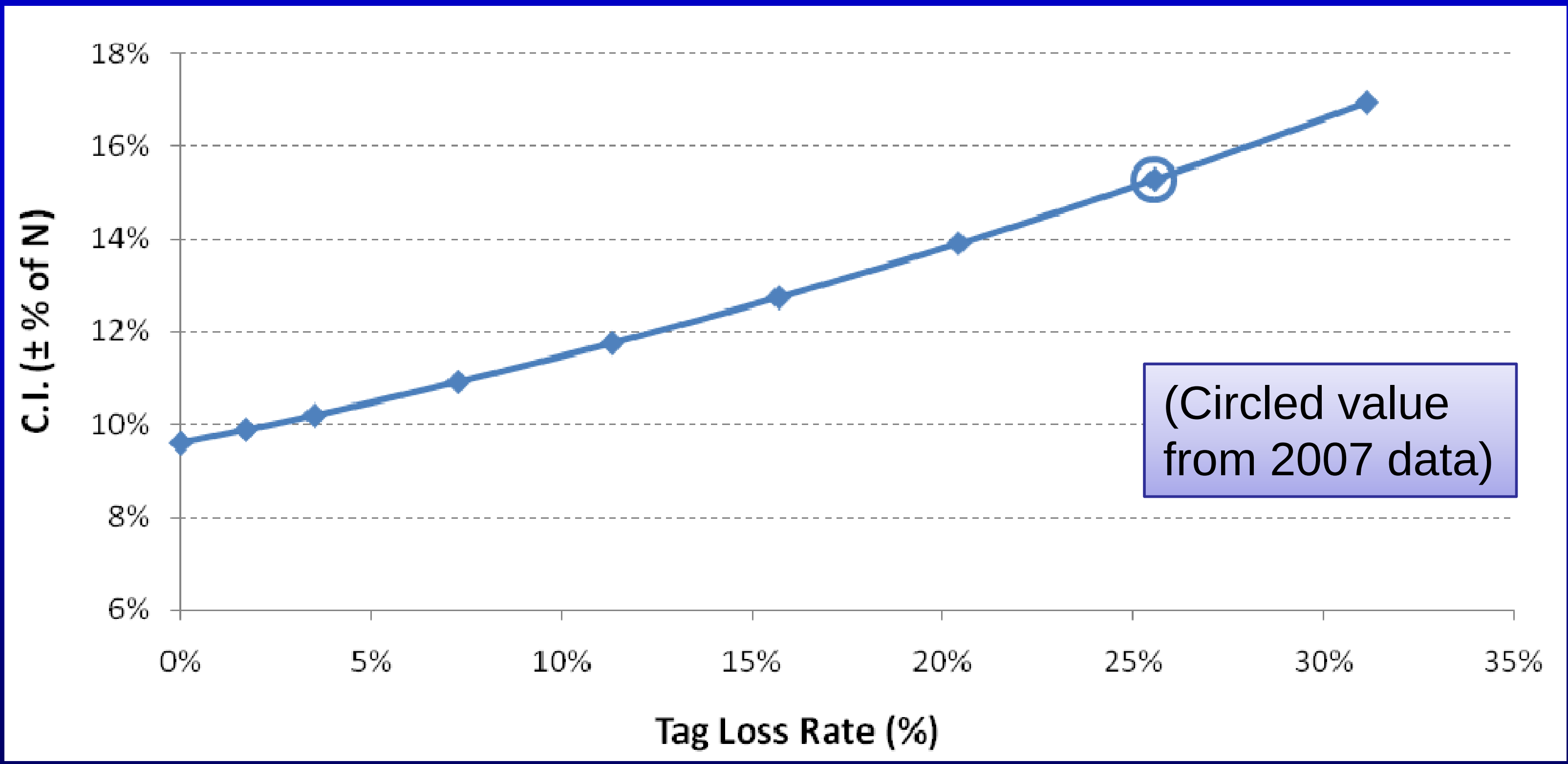


Comparison of Estimates for 2007 Metolius River Kokanee Mark-Recapture Data

	q	Std. Dev.	N	95% C.I.
Petersen Estimators (assumes no tag loss)	n/a	n/a	135,816	11.3% of N
Petersen Estimators (corrected for q)	25.9%	n/a	105,885	11.1% of N
Likelihood Model (corrected for q and Var(q))	25.6%	5.90% (C.I. = 39% of q)	106,630	15.4% of N

Effect of Tag Loss

Effect of tag loss rate on C.I. of N (1.96 * Std. Dev.), we tested alternative values for D_1 and D_2; D = 51, M = 3,298 and C = 11,444 constant, and R recalculated to keep $\hat{N} \approx$ 107,000.



Binomial-Hypergeometric Likelihood Model

Model is available to the public at: "http://www.critfc.org/tech/08-07report.html" – zip file with executable files for the calculation program, a data input file and a tutorial

Caveat: the model requires the assumption that no double-tagged fish lose both tags ($D_0 = 0$)

- cannot know D_0
- assumption acceptable if q is relatively low:

$$D_0 = q^2 * D = \text{very small}$$

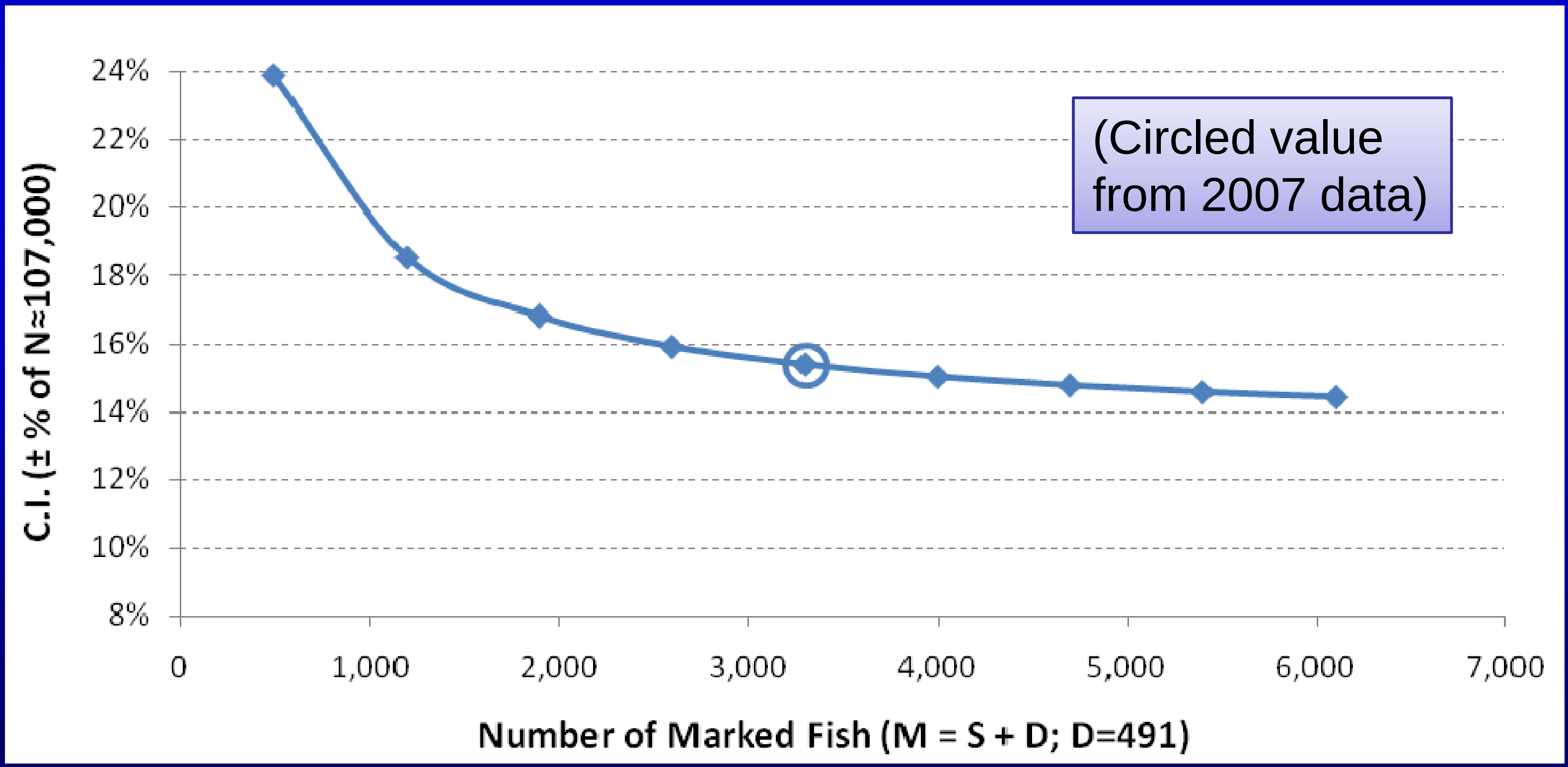
- but, as q increases, the model's estimate of N will be biased high, and variance biased low

Binomial-Hypergeometric Likelihood Model

- The model also has utility for optimizing field protocols:
    - Obtain estimated and/or empirical mark-recapture data, and on the effort (primarily labor) required for the marking and recapture activities
    - Test alternative scenarios with model
    - Perform a cost-benefit analysis - choose a scenario which provides the “best” balance between precision of the abundance estimate and cost to perform the study
- We tested 2007 protocols with 2007 data:

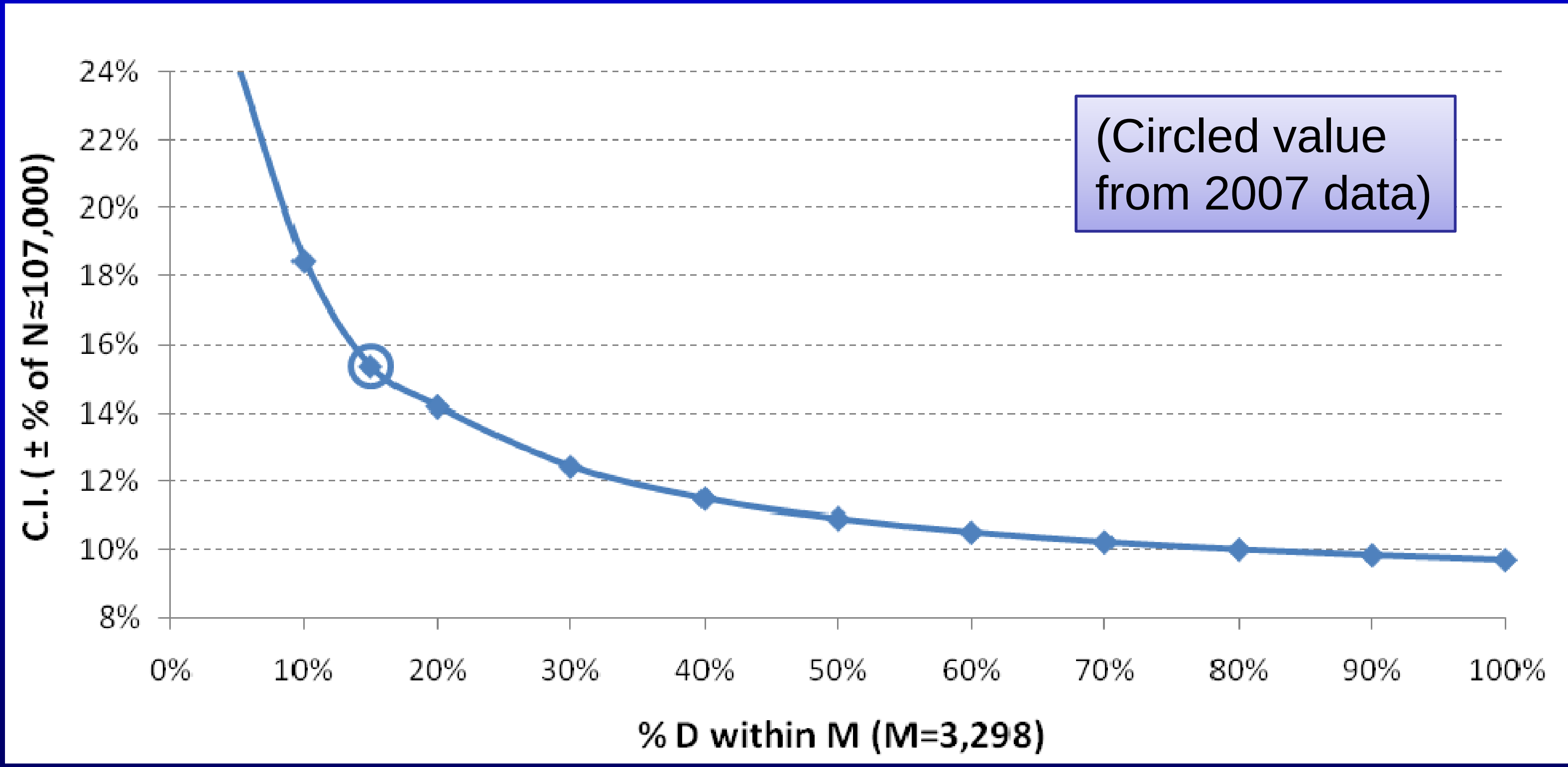
Effect of Change in M_S

Effect of alternative values for M_S on C.I. of N - values for M_D = 491, D_1 = 21, D_2 = 30, C = 11,444 and $\hat{N} \approx$ 107,000 remained constant.



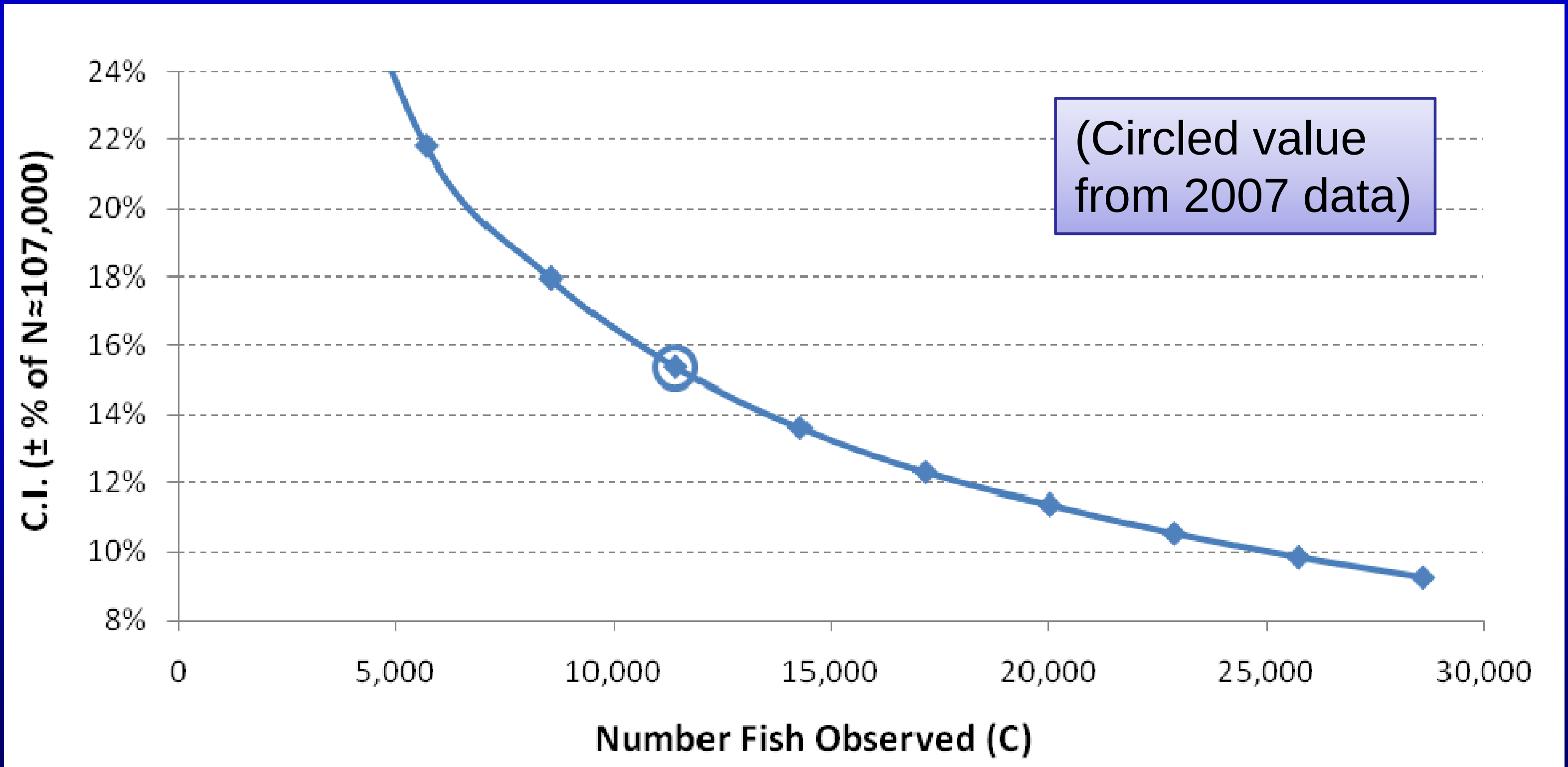
Effect of Change in D

Effect of alternative values for the proportion of double-tagged fish (D) on the C.I. of $\hat{N}$ - values of M = S + D = 3,298 and C = 11,444 constant, and D1, D2, S_R and R changed proportionately.



Effect of Change in C

Effect of change in C (survey effort) – values of M = 3,298, and $\hat{N} \approx$ 107,000 remained constant , and D_1, D_2, R changed proportionately with C.



Recommendations for Metolius Kokanee Mark-Recapture Protocol

- Cost of 2007 Marking and (Re)Capture effort translated into person-days of work
- We recommended 3X increase in the proportion of double-tagged fish (D) and reduction (of C) from 3 to 2 spawning ground surveys
- Result would have been a decrease in C.I. of abundance ($\hat{N}$) from 15.4% to 11.7% , and a savings of 20% in labor

Binomial-Hypergeometric Likelihood Model Version 2

Project in 2009 to improve functionality and form of the model:

1. Modify to accept D_1 and D_2 input data for both Case I and Case 2 designs, and to accept estimated values for q and Var(q) from previous studies

2. Improve “user-friendliness” and “user-foolproofness” - adapt model to internet web-based interface, and provide input and output data within same file

www.critfc.org/tech/08-07report.html

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