2. Mark-recapture methods: an introduction

$$\hat{N} = \frac{(n_1+1)(n_2+1)}{(m_2+1)} - 1$$

- Capture and marking
- The basis of estimating population size (abundance)
  - Assumptions
- Exploring your data

Individual recognition data are used:

- To investigate movement patterns
- To investigate social structure
- To estimate birth rates
- To estimate survival rates
- To estimate population size

$\left.\begin{array}{l}\text{To estimate birth rates}\\ \text{To estimate survival rates}\\ \text{To estimate population size}\end{array}\right\}$ Mark-recapture methods

- Capture and marking …

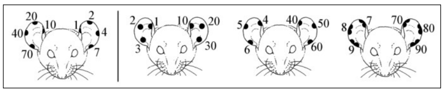
Traps and nets

Photo-identification

Tags and collars

Banding

Clipping



Branding

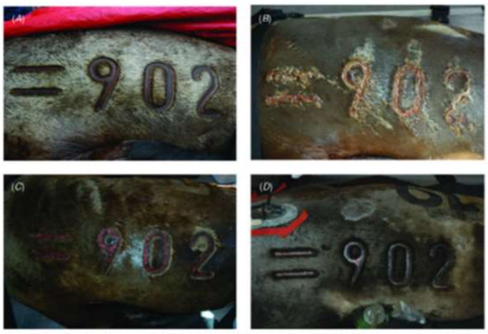


Fig. 1. Stages of hot-brand healing in a juvenile Steller sea lion (*Eumetopias jubatus*), shown as (*A*) day of brand, (*B*) one week post-brand, (*C*) three weeks post-brand, and (*D*) eight weeks post-brand.

Natural markings

Petersen 2-sample estimator of population size

- Capture, mark and release a sample of animals (n_1)
- Allow population to mix
- Capture a second sample of animals (n_2)
- Determine how many are already marked, i.e. recaptured (m_2)
- Equate the proportion marked in 2nd sample with the proportion marked in the population (N): $\boxed{\frac{m_2}{n_2} = \frac{n_1}{N}}$
- Population size is estimated as: $\boxed{\hat{N} = \frac{n_1 n_2}{m_2}}$
- or: $\boxed{\hat{N} = \frac{n_1}{p_2}; \quad p_2 = \frac{m_2}{n_2}}$ where p_2 is the probability of capture in the second sample

Chapman-modified Petersen estimator

- To minimize small sample size bias (positive)

$$\hat{N} = \frac{(n_1+1)(n_2+1)}{(m_2+1)} - 1$$

Petersen

$$\hat{N} = \frac{n_1 n_2}{m_2}$$

- Variance of estimate

$$\text{var}_{\hat{N}} = \frac{(n_1+1)(n_2+1)(n_1-m_2)(n_2-m_2)}{(m_2+1)^2(m_2+2)}$$

- Standard Error of estimate

$$SE_{\hat{N}} = \sqrt{\text{var}_{\hat{N}}}$$

- Coefficient of Variation of estimate

$$CV_{\hat{N}} = \frac{SE_{\hat{N}}}{\hat{N}}$$

Two-sample example

	S_1	S_2
Alpha	1	0
Bravo	1	1
Charlie	1	1
Delta	1	0
Echo	1	1
Foxtrot	1	0
Golf	1	0
Hotel	1	0
India	0	1
Juliet	0	1
Kilo	0	1
	8	6

$n_1 = 8 \quad n_2 = 6 \quad m_2 = 3$

$$\hat{N} = \frac{(8+1)(6+1)}{(3+1)} - 1 = 14.75 \quad = 15$$

$$\text{var}_{\hat{N}} = \frac{(8+1)(6+1)(8-3)(6-3)}{(3+1)^2(3+2)} = 11.81$$

$$SE_{\hat{N}} = \sqrt{11.81} = 3.43$$

$$CV_{\hat{N}} = \frac{3.43}{14.75} = 0.23 \quad \boxed{23\%}$$

Confidence intervals

- Typically, the 95% confidence interval around the mean is represented by: *±1.96 x Standard Error*
- For abundance estimates we need to calculate in a different way:
  *95% confidence interval = N/**c** - N x **c***
- where $c = e^{1.96\sqrt{\ln(1+CV_{\hat{N}}^2)}}$
- E.g. if N = 1,000 and c = 2
  95% confidence interval = 500 - 2,000
- This is a log-normal 95% confidence interval
  - **Note** that the interval is asymmetrical

Data required for mark-recapture population size

- For each sampling occasion:
  - Whether or not each animal was captured
    - Capture histories
- Information on capture effort is not required
  - Effort is equivalent to capture probability
  - Which is estimated by the models

Animal	S_1	S_2	S_3	S_4	S_5	**…**
Alpha	1	0	0	0	0	…
Bravo	1	0	1	0	1	…
Charlie	1	0	0	0	0	…
Delta	1	1	0	1	0	…
Echo	1	0	0	1	0	…
Foxtrot	0	1	0	0	0	…
Golf	0	1	0	0	1	…
Hotel	0	1	1	0	0	…
India	0	0	1	0	1	…
Juliet	0	0	1	1	0	…
Kilo	0	0	1	0	0	…
Lima	0	0	0	1	0	…
Mike	0	0	0	1	0	…
November	0	0	0	0	1	…
Oscar	0	0	0	0	1	…
…	…	…	…	…	…	…

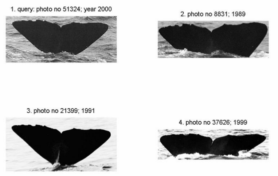
Multi-sample estimators of population size

- Closed population models
  - If we can assume that the population does not change during the study
    - No birth, death, permanent immigration or emigration
    - Population size remains constant
- Open population models
  - Appropriate if the population is changing during the study
    - But often difficult to apply to estimate population size
  - Mostly used to estimate <u>survival rates</u>

Mark-recapture assumptions about the data

- Marks are unique (no ‘twins’)

- Marks cannot change or be lost



- Marks are recognized on recapture and are correctly reported and recorded

Mark-recapture assumptions made by models

- In the simplest models:
  - Marking does not affect future catchability
  - All animals have the same probability of being captured on each sampling occasion
  - Usually assume complete mixing between sampling occasions
  - **Note** that these assumptions can be relaxed in some models
- For closed population models, the population is closed to:
  - Births, deaths, permanent immigration and emigration
  - But <u>temporary</u> immigration/emigration is usually not a problem

Common violations of assumptions about the data

- Insufficient information in the mark to guarantee no ‘twins’
  - Two different animals are matched as being the same (false positives)
  - Population size is <u>under</u>-estimated
- Marks fall off, or fade, or change (mark loss)
  - Missed recaptures (false negatives)
  - Population size is <u>over</u>-estimated

- Marks are mis-recorded or mis-reported
  - Either a new animal is created when it should be a recapture (false negative)
    - Population size is over-estimated
  - Or a new animal is mistaken for an existing animal (false positive)
    - Population size is under-estimated

$$\hat{N} = \frac{n_1 n_2}{m_2}$$

Common violations of assumptions made by models

- Marking causes a change in capture probability
  - 'Trap happiness' – population size is under-estimated
  - 'Trap shyness' – population size is over-estimated
- Individual differences (heterogeneity) in capture probabilities
  - Three causes:
    - Animals don't mix randomly (differences in area preferences)
    - Some animals are more difficult to capture than others (behaviour)
    - Some animals are more distinctively marked than others
  - The result is that some animals are captured more often than expected and others are captured less often than expected
  - The overall effect is that population size is under-estimated

$$\hat{N} = \frac{n_1 n_2}{m_2}$$

Common violation of assumptions made by closed models

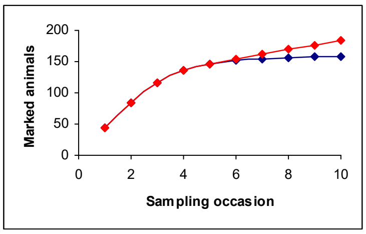
- Population is <u>not</u> closed
  - Births and deaths occurring
    - Proportion of marked animals in the population is diluted over time
    - Population size is over-estimated
  - Could also occur with permanent immigration or emigration
  - Temporary immigration or emigration …
    - If random, usually not a problem
    - If non-random, can introduce bias

Photo-identification

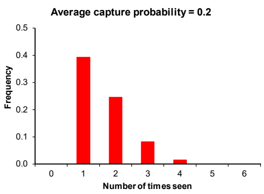
- No physical capture or marking ☺
  - Marking should not affect future catchability ☺
- Appropriate marks are unique and cannot be lost ☺
  - But not all animals may have marks ☹
  - And marks may change ☹
- Recognition of marks is not certain ☹
  - Distinctness of marks
  - Quality of photographs
- Animals have different capture probabilities ☹
  - Probability of being encountered
  - Probability of being photographed
  - Probability of being recognized

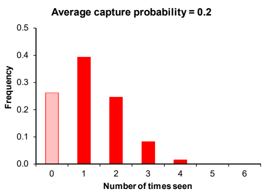
Discovery curves

- Cumulative number of unique individuals plotted against sampling occasion
  - Indication of how much of the population has been marked

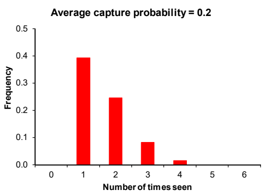


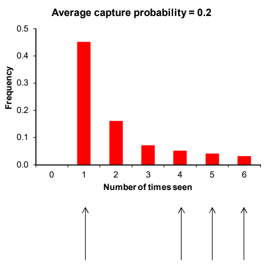
Frequency of capture





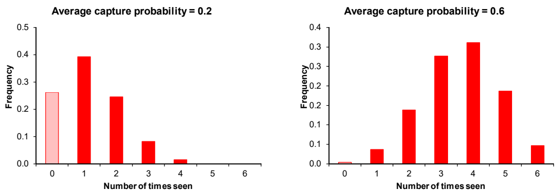
Frequency of capture





Heterogeneity of capture probabilities

Frequency of capture



Mark-recapture methods - summary

- Method of capture
- Method of marking

} Photo-identification 

- Basis for analysis
  - Equating proportion of marked animals in sample and population
- Capture histories are sufficient data for analysis
- Assumptions …
- Closed and open population models
  - Assumptions, advantages and disadvantages
- Get to know your data
  - Discovery curves and frequency of capture