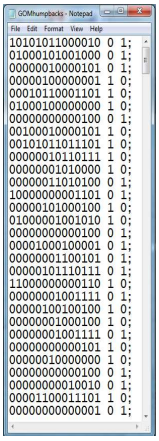



## 7. Mark-recapture analytical methods:
### open population models

$\hat{\phi}$?

$\hat{N}$?

## Multi-sample estimation models

- Closed population models to estimate <u>population size</u>
  - If we can assume that the population does not change during the study
    - No birth, death, permanent immigration or emigration
    - Population size remains constant
  - For marine mammals, population closure with a year is typically assumed
- Open population models
  - Appropriate if the population is changing during the study
    - i.e. over multiple years
  - But often difficult to apply to estimate <u>population size</u>
  - Mostly used to estimate <u>survival rates, $\phi$</u>

## Mark-recapture assumptions (revisited)

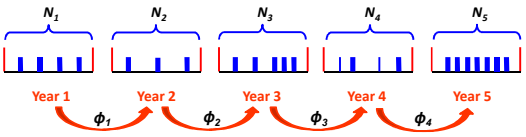
- Marks are unique (no 'twins')
- Marks cannot change or be lost
- Marks are recognized on recapture and are correctly reported and recorded
- In the simplest models:
  - Marking does not affect future catchability ***or survival***
  - All animals have the same probability of being captured on each sampling occasion (i.e. there is no heterogeneity)
  - ***All animals have the same probability of surviving from one sampling occasion to the next***
  - **Note** that these assumptions can be relaxed in some models

## Open population models

- Appropriate for long-term studies
  - Because population is changing over time
- Estimation of survival rate is usually robust
  - Because estimation is directly from data on captured animals
- Range of user-defined models for analysis in *MARK*
- Estimation of population size is typically less robust
  - Because estimation uses data from captured animals to make inferences about the number of animals never captured
  - Makes more assumptions about the data
- Open models cannot take account of heterogeneity
  - Estimates of survival are fairly robust to this
  - Estimates of population size are not robust to heterogeneity, and will likely be negatively biased

## Robust design models

- Combination of open and closed models
- Use primary and secondary sampling occasions
  - Primary sampling occasions are typically years
  - Secondary sampling occasions are days, weeks, months within each year




- The closed models estimate population size *within* years
- The open models estimate survival *between* years
- Also allow estimation of temporary immigration/emigration

## Birth and death: the basis of life history

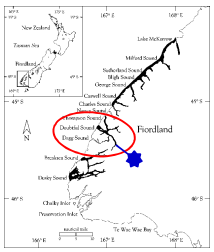



## Why estimate birth and survival/mortality rates?

- To describe a species' life history
  - Birth & death rates, sex ratio
  - Life expectancy, reproductive potential
- To study population dynamics
  - What are the causes of observed changes in populations?
- To use in population models
  - To estimate rates of population change
  - To explore extinction probabilities
    - Population Viability Analysis (PVA)
- Knowledge of life history can focus conservation efforts …

## Doubtful Sound bottlenose dolphins

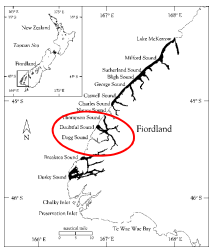
- Small population of bottlenose dolphins
- Hydro-electric power plant
- Intensive tourism activities

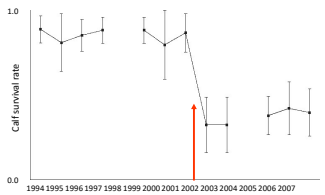



- Population declined since late-1990s
- Why?

## Doubtful Sound bottlenose dolphins

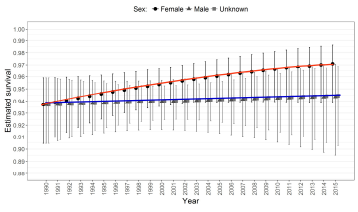
- Adult survival rate = 0.94 (95% CI: 0.92 - 0.95)
- Calf survival rate: step change from an average of 0.86 to 0.38
- Focus has been on dolphin-watching as the cause
- Second hydro-electric tail-race tunnel opened in 2002 …




Currey *et al.* (2007) Pacific Cons Biol 13: 265-273
Currey *et al.* (2009) Aquat Cons Mar Fresh Ecol 19: 658-670

## Scottish east coast bottlenose dolphins



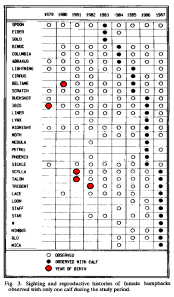

- Survival rate estimated over 25 years
  - Male: steady at 0.94
  - Female: increased from 0.94 to 0.97
    - Mortality rate halved from 6% to 3%

Arso Civil, M. *et al.* (2018). Ecology and Evolution 2018: 1-12. doi: 10.1002/ece3.4772.

## Birth rates from photo-id data

- Gulf of Maine humpback whales

Calving interval



Age at first parturition

- Age at sexual maturity:
  - 4 - 6 years
- Mean inter-birth interval:
  - 2.4 years
- Birth rate:
  - Reciprocal of inter-birth interval
  - 0.42 calves per adult female per year

## Bottlenose dolphin calving histories

| ID # | 1987 | 1988 | 1989 | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | Calves |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 4 | | | 1 | ● | 0 | 1 | 1 | ● | 1 | 1 | 0 | 0 | 0 | ● | 1 | 1 | 1 | 1 | 0 | ● | 1 | 1 | 0 | 0 | 0 | 0 | 4 |
| 9 | | ● | 1 | 1 | 1 | 0 | 0 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | ● | 1 | 0 | 1 | 1 | 1 | 1 | 2 |
| 11 | | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 1 | 1 | ● | 1 | 1 | 1 | 1 | ● | 1 | 1 | ● | 1 | ● | 4 |
| 24 | | | 1 | 1 | 1 | ● | 0 | ● | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 |
| 27 | | ● | 1 | 1 | ● | 1 | 1 | 1 | 1 | 0 | ● | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 |
| 30 | | | ● | 1 | 1 | ● | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | ● | 1 | 1 | 1 | 0 | 1 | 0 | 0 | ● | 1 | 1 | 1 | 4 |
| 31 | | | 1 | 1 | 1 | 1 | 1 | 1 | ● | 1 | 1 | 1 | 1 | 1 | ● | 1 | 1 | 1 | ● | 1 | 1 | 1 | 1 | 1 | 1 | ● | 4 |
| 52 | | | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 1 | 0 | 1 | ● | 1 | 1 | 1 | ● | 1 | ● | 3 |
| 55 | | | 1 | 1 | ● | 1 | 0 | ● | 1 | 0 | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 |
| 58 | | | 1 | 0 | ● | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| 61 | | | 1 | 1 | 0 | 1 | 0 | ● | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | ● | 1 | 1 | 0 | 0 | 0 | 0 | 2 |
| 64 | ● | | 1 | 1 | 1 | 1 | ● | 1 | 1 | 1 | ● | 1 | 1 | 1 | 1 | 1 | ● | 1 | 1 | 1 | ● | 1 | 1 | 1 | 1 | ● | 6 |
| 68 | | | ● | 1 | 0 | ● | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 0 | 1 | ● | 1 | 1 | 3 |
| 79 | | | 1 | 1 | 1 | ● | 0 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 85 | ● | | 0 | ● | 1 | ● | 1 | ● | 1 | 1 | 1 | d | d | d | d | d | d | d | d | d | d | d | d | d | d | d | 4 |

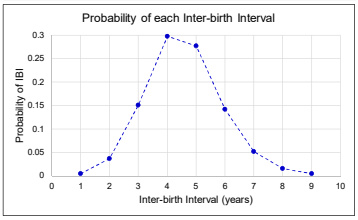
0 = not sighted; 1 = sighted; ● = sighted with newborn calf; d = deceased

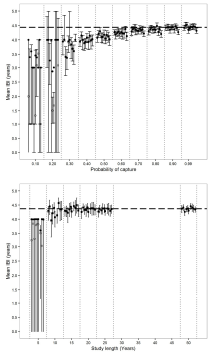
= data used in analysis

Arso Civil, M. *et al.* (2017). Ecosphere 8(4): e01796. doi: 10.1002/ecs2.1796

## Bottlenose dolphin birth rate from a model

- p(birth) ~ YSPB + YSPB$^2$ + ID + year
  - YSPB = years since previous birth



Mean estimated Inter-birth Interval = 4.5 years
Mean birth rate = 0.22 calves per adult female per year

*Mean observed Inter-birth Interval = 3.7 years*

## Mark-recapture survival analysis

- Survival analysis models have two basic parameters:
  - $\phi_i$ = probability of surviving from time *i* to time *i*+1
  - $p_i$ = probability of re-capture at time *i*
- These parameters are estimated from the capture history data
- For two sampling occasions (for illustration):

| | | |
|---|---|---|
| 11 | captured and marked on the 1st occasion; and alive and seen on the 2nd occasion | $\phi_1 p_2$ |
| 10 | captured and marked on the 1st occasion; and either:<br>• alive but not seen on the 2nd occasion, or<br>• dead by the 2nd occasion | $\phi_1(1-p_2)$ $+ (1-\phi_1)$ |

## Summary

- Open population models
  - Robust estimation of survival rate
  - Estimation of population size not robust
    - Cannot account for heterogeneity of capture probabilities
- Calving histories to estimate inter-birth interval
  - and therefore birth rate