Mark-Recapture

Mark-Recapture

- Modern use dates from work by C. G. J. Petersen (Danish fisheries biologist, 1896) and F. C. Lincoln (U. S. Fish and Wildlife Service, 1930)

Useful in estimating:

- a. Size of population
- b. Rate of exploitation
- c. Survival rate
- d. Rate of recruitment

Lincoln-Petersen Estimate

- Applicable to closed populations
- A sample is taken, marked and released back into the population = M
- A second sample is taken of n individuals of which m have marks

Lincoln-Petersen Estimate

- Proportion in sample marked = m/n
- This proportion should be equal to the proportion of marked population (M) to total population (N)
- = M/N
- e.g. M/N = m/n

Lincoln-Petersen Estimate

- Assuming second sample is an unbiased sample of population, then
- $N_{est} = Mn/m$
- This basic model is the point of departure for multitude of more sophisticated (complicated) models.

Chapman's modification

$$N_{est} = \frac{(M+1)(n+1)}{(m+1)}$$

$$Var(N) = \frac{N^2 (n-m)}{(n+1)(m+2)}$$

Rate of Exploitation

- Where the second sample is taken in course of harvesting the population (much of fisheries, waterfowl, control efforts for pests)
- Rate of exploitation (u)
- $u_{est} = m/M$

Assumptions:

- 1. Population is closed (no births or deaths or movements out or in)
- 2. All animals have same probability of being caught in the first sample
- 3. Marking does not affect catchability of an animal
- 4. Second sample is a random sample

Assumptions:

- 5. No loss of tags between samples
- 6. All tags are reported in the second sample

Multiple Mark-Recaptures

- Assuming a closed population Schnabel (1938) and Schumacher & Eschmeyers (1943) developed
- $\Sigma n_i M_i$
- N_k = -------------------
- $(\Sigma m_i) + 1$
- Note: All sums from i=2 to k

Multiple Mark-Recapture

- A great advantage of multiple mark-recapture studies is that we can evaluate some of the critical assumptions
- and apply more complicated models where the simple assumptions are not appropriate.

Probability of Capture

- "Probability of capture is equal and constant for each animal at each trapping occasion."
- Problems:
  - Day to day variation (weather) = time
  - Behavioral effects (trap happy/shy)
  - Individual differences (heterogeneity)

Capture Program

- Models developed to handle these problems based on maximum likelihood (ML) in 50's, 60's, 70's.
- Not applied until 1980's because of difficulty of calculations.
- Otis et al (1978: Wildlife Monograph No.62) developed program CAPTURE to do calculations.

CAPTURE Program: Models

- M_o Constant capture probabilities
- M_t Variation by time =Schnabel
- M_b Behavioral response to trapping
- M_{bh} Behavior and heterogeneity
- M_{th}, M_{tb}, M_{tbh}

CAPTURE Program

- Key requirement is to mark animals individually so that their full capture history can be recorded.
- Numbers vs. density
- Boundary problems

Trapping Web

- Standard approach is to lay out traps in a rectangular grid (See CAPTURE concentric rows of traps)
- Record location of initial capture of each animal.
- Density of captures in centermost circles estimates density using variable circular plot approach.

Open Population

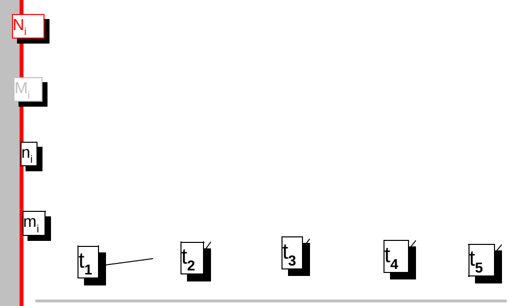
- Limitation of previous methods is assumption of closure (no births, deaths, immigration or emigration).
- Can we estimate for open populations?
- What problem does mortality cause?
- Marked population is unknown because some of these have died.

Open Population

- Jolly (1965) - English statistician and
- Seber (1965) - New Zeland statistician
- independently developed solution for multiple mark-recapture study based on earlier work by:
- Darroch (1959) another English statistician and Cormack (1964) a Scottish statistician.

t_1 t_2 t_3 t_4 t_5

Darroch, Cormack, Jolly & Seber's Idea



Jolly-Seber Model (Often called Cormack-Jolly-Seber)

- Use results of sampling at later time periods to estimate how many of the marked animals were present at an earlier time period.
- To do this we must give each animal an individual mark so that its entire capture history can be recorded.

Capture Recapture Totals

Time	Captured	Recaptures	Released
i	n_i	m_i	R_i
1	54	0	54
2	146	10	143
3	169	37	164
4	209	56	202
5	220	53	214
6	209	77	207

Recapture Matrix

Time of last Capture	Time of Capture 1	2	3	4	5	6
1		10	3	5	2	2
2			34	18	8	4
3				33	13	8
4					30	20
5						43

JS Population Estimate

$$N_i = \frac{n_i M_i}{m_i}$$

- If we don't actually know M_i we can use an estimate of M_i.

JS Survival Estimate

- $$s_i = \frac{M_{i+1}}{M_i + n_i - m_i}$$

JS Estimate of Births

- N_{i+1} = Additions + Survivors from N_i
- $= B_i + N_i s_i$
- rearranging this for births
- $B_i = N_{i+1} - N_i s_i$

JS Marked Population

- How do we estimate the size of the marked population?
- We have to do a mark-recapture estimate of that.
- Use the animals not seen at the first recapture sample but seen later on as our recaptures.
- We do a mark-recapture within a mark-recapture estimate.

JS Marked Population

- M_i actually unknown because of mortality of released animals
- What is largest known group at i that is a subset of M_i ?
- m_i is known so must estimate the rest
- $M_i - m_i$ are the rest

JS Marked Population

- Which of the rest are known to be alive?
- Some of the rest are caught after sample i
- Call these z_i
- z_i = Animals marked previous to sample i, not caught at i, but caught later.

JS Marked Population

- n_i is largest group of individuals known to be alive at sample i and it is comparable to $(M_i - m_i)$, the "rest"
- Denote by r_i the number of n_i observed after sample i.
- r_i is some fraction of n_i

JS Marked Population

- r_i / n_i should be comparable to
- $z_i / (M_i - m_i)$
- Setting these equal to each other and solving for M_i
- $$M_i = \frac{z_i n_i}{r_i} + m_i$$

Recapture Matrix

Time of last Capture	Time of Capture 1	2	3	4	5	6
1		10	3	5	2	2
2	Z_3 =		34	18	8	4
3		r_3=		33	13	8
4					30	20
5						43

Marked Population at t=3

- r_3 = 33+13+8 = 54
- z_3 = 5+2+2+18+8+4 = 39
- n_3 = 169
- m_3 = 37
- $z_3\ n_3$ 39*169
- M_3 = --------- + m_3= ------ + 37=155.5
- r_3 54

Population at t=3,4

- M_4 = (202*37/50)+56 = 205.5
- $N_3 = n_3M_3/m_3$=169*155.5/37 = 710
- N_4 = 209*205.5/56 = 767
- $S_3 = M_4/(M_3+n_3-m_3)$
- = 205.5/(155+169-37)=0.72
- $B_4=N_4-N_3*S_3$=767-710*0.72=256

Upshot?

- For this real example we can estimate population size, at each sample except last, as well as birth rate and death rate between all surveys except last.
- Variance of each estimate and its standard error can be calculated in MARK or JOLLY software programs.
- It takes large numbers of marked animals and recaptures for decent estimates.

Closed vs. Open Estimators?

- Closed (CAPTURE) allows us to test more of the assumptions and estimate correctly even if some assumptions aren't met.
- Open (MARK) isn't biased by lack of closure but can't deal with all the problems that closed estimators handle.
- Could they be combined?

Combination of Open and Closed Models = Pollock's Robust Design

- Ken Pollock (prof at North Carolina State Univ.) developed a clever, robust design in 1982 which:
  - applies methods assuming closed popn during closely spaced multiple recapture samples and
  - applies Darroch-Cormack-Jolly-Seber methods for open popn during wider intervals between intense samples above.
- MARK by Gary White incorporates this combined approach, but now you really need lots of data!