BIOL 410 Population and Community Ecology

Mark Recapture

Calculating vital rates

Mark Recapture methods

1. Capture and mark individuals
   - Radio transmitters, PIT tags, ear tags, physical features, genetics, etc.
2. Recapture or resight random sample of individuals during subsequent surveys
3. Calculate the proportion of new and previously captured/ sighted individuals.

Mark-Recapture Methods

Three Standard Methods

1. **Petersen Method** – closed population, single recapture event

2. **Schnabel Method** – closed population, multiple recapture events

3. **Jolly-Seber Method** – open population, multiple censusing events

- Closed population: doesn't change in size during study
- Open population: population changes in size

Petersen Method

One mark and one recapture session

$$\frac{\boldsymbol{N}}{\boldsymbol{M}} = \frac{\boldsymbol{C}}{\boldsymbol{R}}$$

First sample

Second sample

Variables

M = Number of individuals marked during the first sample

C = Total number of individuals captured during the second sample

R = Number of individuals in the second sample that were marked

N = Size of the population at the time of Marking.

Petersen Method

- If the number of recaptures is less than 7 (R<7), add the value of 1 to each of the number Marked, Captured and Recaptured

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

Petersen - Confidence Intervals

How you Calculate Confidence Intervals depends on number of **R**ecaptures relative to Total **C**aptures at second marking session.

- If the proportion of recaptured individuals is greater than 10% of the total captures on the second sampling period (R/C>0.1), then use a **Binomial Confidence Interval**.

- If R/C is *less* than 10%, but the number of recaptures is greater than 50 (R>50), then use a **Normal Approximation**

- If R/C is *less* than 10% and R<50, you use a **Poisson Confidence Interval**

Petersen - Confidence Intervals

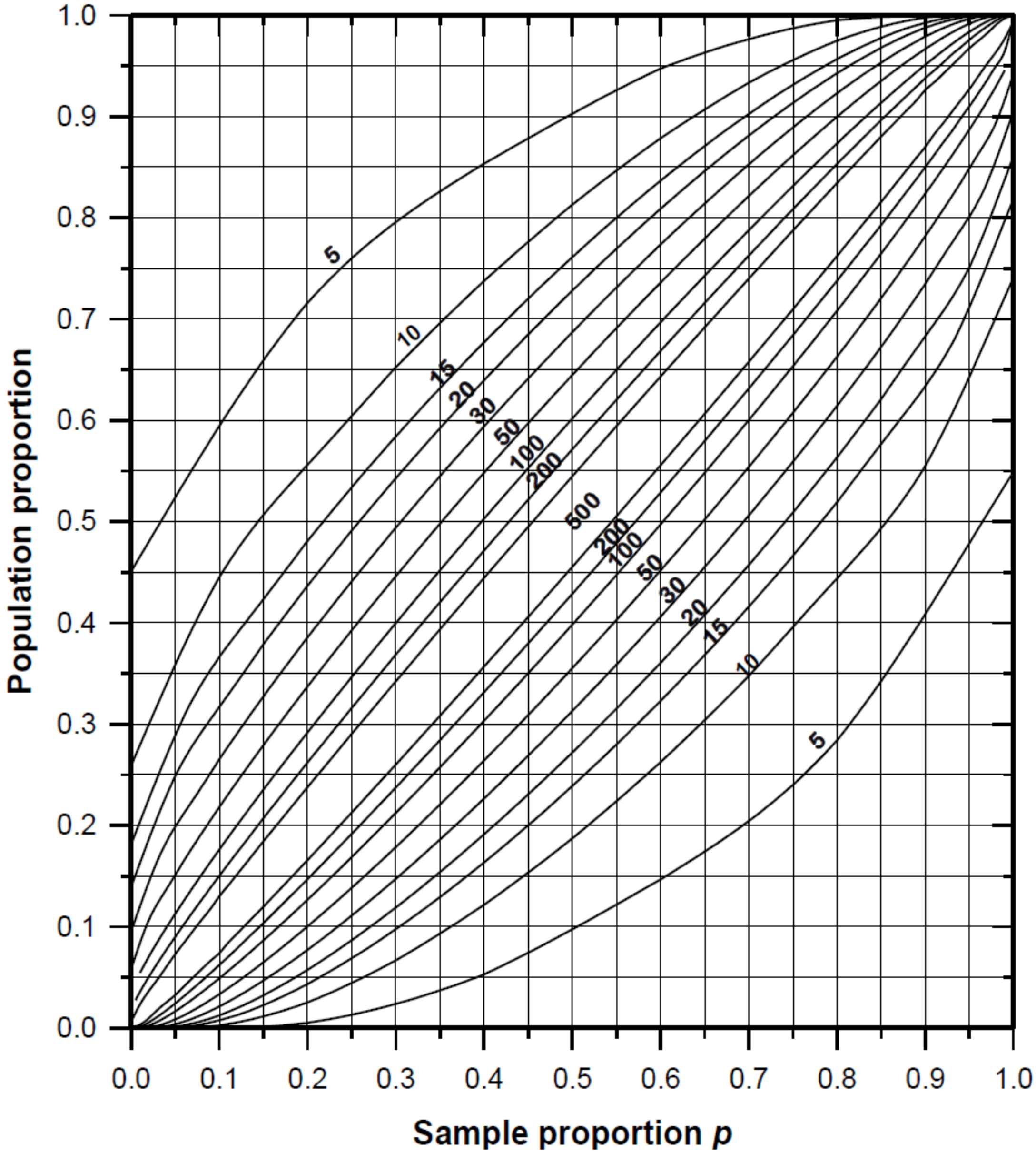
Binomial Confidence Interval

- X-axis = Recaptures /Captures
- Lines –Captures
- Y-Axis – Upper and lower Confidence Intervals for a given R/C.

$$\widehat{N} = \frac{CM}{R}$$

$$Lower\ 95\%\ CI\ on\ \widehat{N} = \frac{1}{Upper\ pop.proportion} M$$

$$Upper\ 95\%\ CI\ on\ \widehat{N} = \frac{1}{Lower\ pop.proportion} M$$



Petersen - Confidence Intervals

Poisson Confidence Interval

- **X in table corresponds to number of Recaptures in your sample (R)**
- **Sub upper and lower values into estimate of N for low recaptures to get upper and lower CI**

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

TABLE 2.1 CONFIDENCE LIMITS FOR A POISSON FREQUENCY DISTRIBUTION. Given the number of organisms observed (x), this table provides the upper and lower limits from the Poisson distribution. Do not use this table unless you are sure the observed counts are adequately described by a Poisson distribution.

	95%		99%			95%		99%	
x	Lower	Upper	Lower	Upper	x	Lower	Upper	Lower	Upper
0	0	3.285	0	4.771	46	34.05	60.24	29.90	65.96
1	0.051	5.323	0.010	6.914	47	34.66	61.90	31.84	66.81
2	0.355	6.686	0.149	8.727	48	34.66	62.81	31.84	67.92
3	0.818	8.102	0.436	10.473	49	36.03	63.49	32.55	69.83
4	1.366	9.598	0.823	12.347	50	37.67	64.95	34.18	70.05
5	1.970	11.177	1.279	13.793	51	37.67	66.76	34.18	71.56
6	2.613	12.817	1.785	15.277	52	38.16	66.76	35.20	73.20
7	3.285	13.765	2.330	16.801	53	39.76	68.10	36.54	73.62
8	3.285	14.921	2.906	18.362	54	40.94	69.62	36.54	75.16
9	4.460	16.768	3.507	19.462	55	40.94	71.09	37.82	76.61
10	5.323	17.633	4.130	20.676	56	41.75	71.28	38.94	77.15
11	5.323	19.050	4.771	22.042	57	43.45	72.66	38.94	78.71
12	6.686	20.335	4.771	23.765	58	44.26	74.22	40.37	80.06
13	6.686	21.364	5.829	24.925	59	44.26	75.49	41.39	80.65
14	8.102	22.945	6.668	25.992	60	45.28	75.78	41.39	82.21
15	8.102	23.762	6.914	27.718	61	47.02	77.16	42.85	83.56
16	9.598	25.400	7.756	28.852	62	47.69	78.73	43.91	84.12
17	9.598	26.306	8.727	29.900	63	47.69	79.98	43.91	85.65
18	11.177	27.735	8.727	31.839	64	48.74	80.25	45.26	87.12
19	11.177	28.966	10.009	32.547	65	50.42	81.61	46.50	87.55
20	12.817	30.017	10.473	34.183	66	51.29	83.14	46.50	89.05
21	12.817	31.675	11.242	35.204	67	51.29	84.57	47.62	90.72
22	13.765	32.277	12.347	36.544	68	52.15	84.67	49.13	90.96
23	14.921	34.048	12.347	37.819	69	53.72	86.01	49.13	92.42
24	14.921	34.665	13.793	38.939	70	54.99	87.48	49.96	94.34
25	16.768	36.030	13.793	40.373	71	54.99	89.23	51.78	94.35
26	16.77	37.67	15.28	41.39	72	55.51	89.23	51.78	95.76

Petersen - Assumptions

Assumptions of the Petersen Method

- The Population is closed, so that N is constant
- All animals have the same chance of getting caught in the first sample
- Marking individuals does not affect their catchability
- Animals do not lose marks between the two sampling periods
- All marks are reported upon discovery in the second sample

Schnabel Method

Extension of Petersen Method with multiple marking events

- **Number of Marked individuals accumulate with each time interval.**

$$\widehat{N} = \frac{\sum_t (C_t M_t)}{\sum_t R_t}$$

- **C_t = Total number of individuals caught in sample *t***
- **R_t = Number of individuals already marked when caught at sample *t***
- **U_t = Number of individuals marked for first time and released in sample *t***
- **M_t = The number of marked individuals in the population just before sample *t* is taken. (essentially, the cumulative number of U_t up to t-1)**
  - **M6 = U1 + U2 + U3 + U4 + U5 + U6**

Schnabel – Confidence Intervals

If $\sum R_t$ < 50, use values from a Poisson table

If $\sum R_t$>50, calculate with a normal approximation

$$\frac{1}{\hat{N}} \pm t_\alpha \text{S.E.}$$

where S.E. = standard error of $1/N$

t_α = value from Student's t-table for (100 - α)% confidence limits.

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$$Variance\left(\frac{1}{\hat{N}}\right) = \frac{\sum R_t}{(\sum C_t M_t)^2}$$

$$Standard\ error\ of\left(\frac{1}{\hat{N}}\right) = \sqrt{Variance\left(\frac{1}{\hat{N}}\right)}$$

Vital rates

- Fundamental parameter of population change: birth rates, death rates
  - Birth rates: number of individuals born/individual
  - Death rates: number of individuals die/individual
    - Probability of survival = 1 – P(mortality)

- Why are population ecologists interested in vital rates?

Birth rates: Fecundity

- “number of female offspring produced per adult female per unit of time”

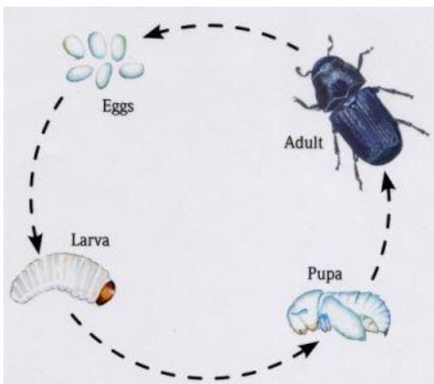
- Often generalized to the number of young produced per female per unit of time
- If interested in population productivity then must know the sex ratio of the young
- “Young” often constituted as:
  – Number of zygotes
  – Number of viable young
  – Number of individuals recruited into next time step
- Natality is synonymous with birth rate
  – Ratio of live births in area to population of area (births/1000 individuals/year)

Measuring birth rates

- Direct methods
  - Observe number of offspring at natal site
    - Some mammal and birds (eggs, litter size)
    - Link between adult and offspring (somewhat)
  - Observe number of young at breeding site
    - Weak or no link between adult and offspring
  - Placental scars from managed mammal populations

Measuring birth rates

- Indirect methods
  - Evidence of offspring at different stages



Bull trout

Upstream spawning trap

Female weight
Gonadal weight

Egg weight
GSI estimate

Redd count

Estimate fry per redd

Measuring mortality rates

- Finite Survival
  - Alive or dead (finite)
    - P(mortality) = 1 – P(survival)
  - # of individuals alive at end of a time period / # of individuals alive at beginning of a time period
- Finite survival rate (e.g. year)

$$\hat{S}_0 = \frac{N_1}{N_0} = \frac{80}{100} = 80\%$$

- Year is a convenient period, but could be any duration (e.g. month, 17 days, etc.)

Measuring mortality rates

- Finite survival rate
  - Converting from observed rate to mortality over standard time
    - E.g. 54 of 67 individuals alive over 42 day period (cohort frogs)

$$Adjusted\ \hat{S}_0 = Observed\ \widehat{S}_0^{(t_s/t_0)}$$

    - t_s = standardized time interval (e.g. 30 days)
    - t_o = observed time interval (e.g. 42 days)

- Standardize to 30 day period

$$Observed\ \widehat{S}_0^{(t_s/t_0)} = Observed\ \widehat{S}_0^{(t_s/t_0)} = \left({}^{54}/_{67}\right)^{\left({}^{30}/_{42}\right)} = 0.8^{0.71} = 0.86$$

Measuring mortality rates

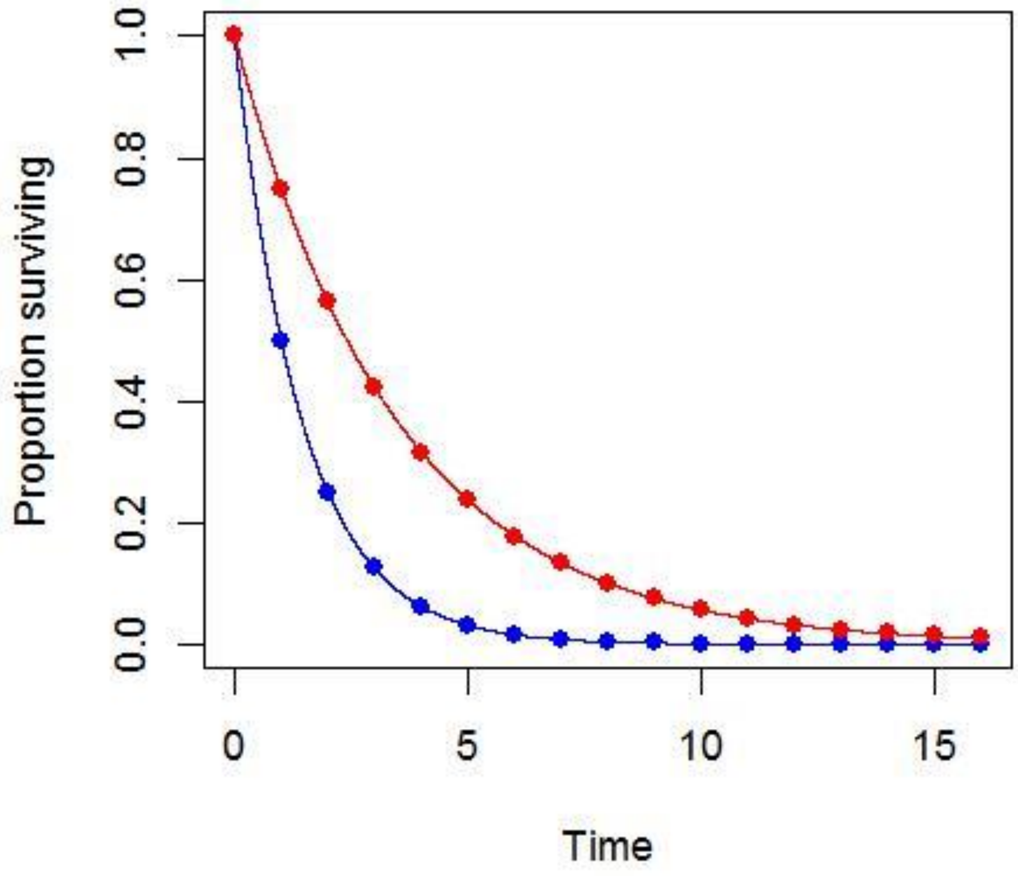
- Instantaneous survival rate
  - If number of deaths over a very short time is proportional to the number of individuals

$$\frac{dN}{dt} = iN$$

Instantaneous mortality rate
Always a negative number

Integral form $$N_t = N_0 e^{it}$$

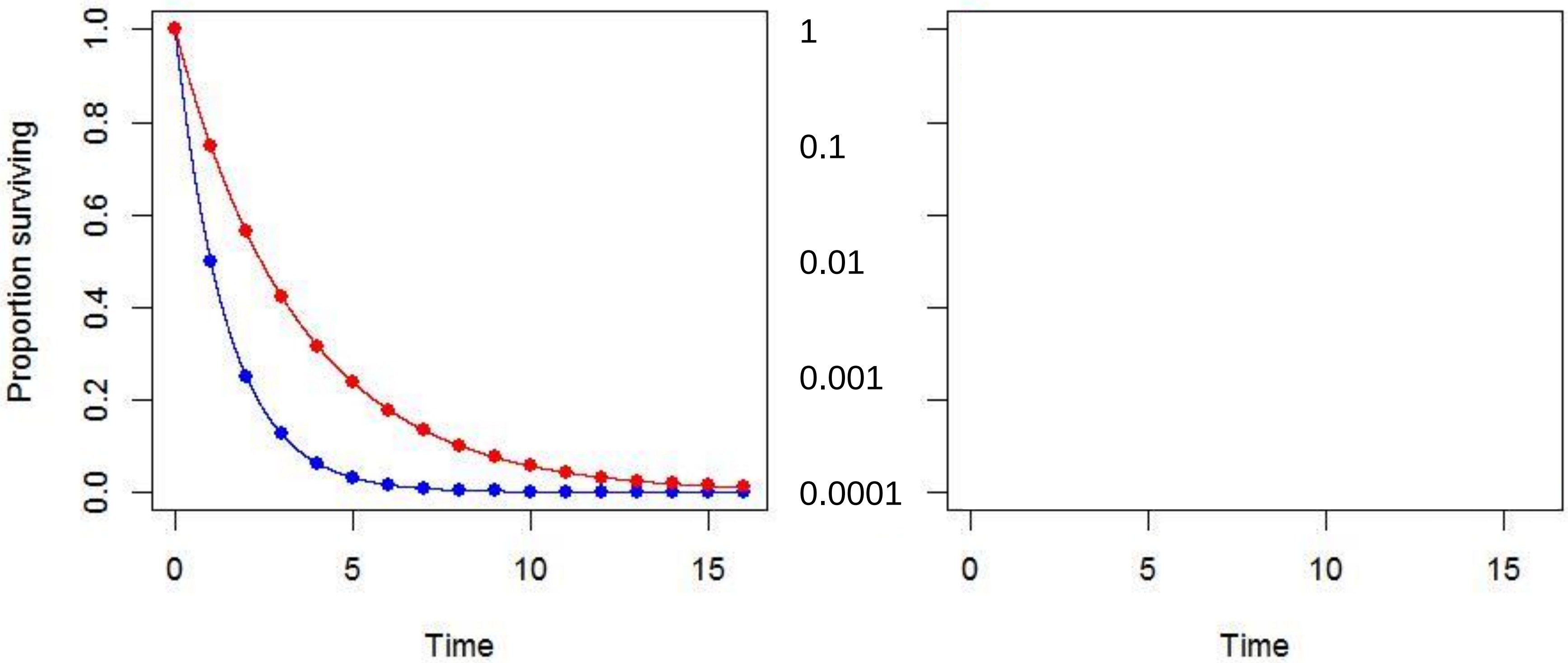
Finite survival rate



$$\hat{S}_0 = \frac{50}{100} = 50\%$$

$$\hat{S}_0 = \frac{75}{100} = 70\%$$

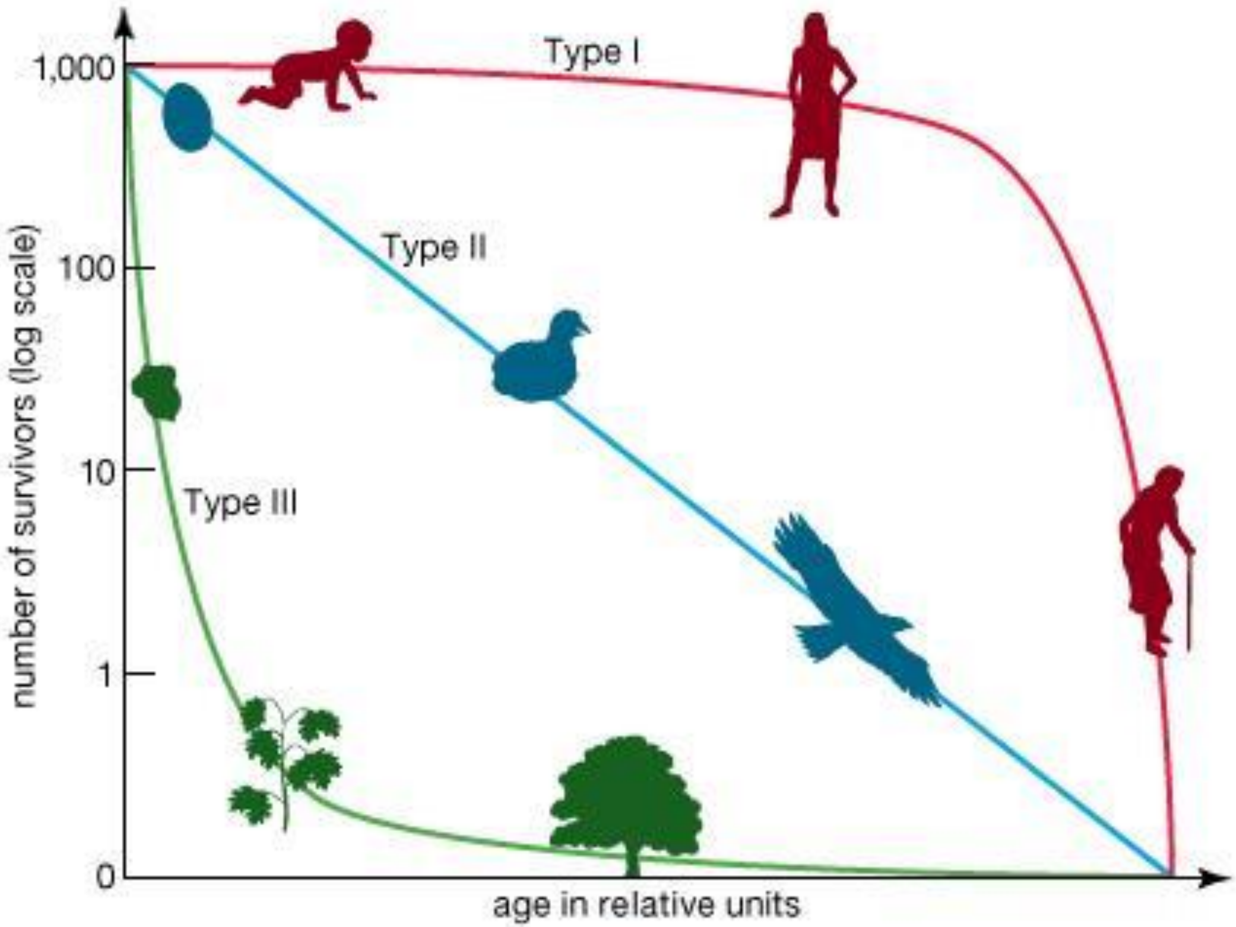
Survival rates



$$N_t = N_0 e^{it}$$

Estimating i

Survivorship curves



Measuring survival/mortality rates

- For some species survival is the dominant determinant of populations change

- Survival can be a difficult process to quantify in wild populations
- Survival of captive animals is usually a poor indicator of survival of wild animals

Methods for estimating survival rates

1. Life history table
   - Age-specific description of a mortality schedule
   - Cohort life history table superior to static life table

x	*S(x)*	*l(x)*	*g(x)*	*b(x)*	*l(x) b(x)*
0	500	1.0	0.8	0	0.0
1	400	0.8	0.5	2	1.6
2	200	0.4	0.25	3	1.2
3	50	0.1	0	1	0.1
4	0	0		0	0.0

Methods for estimating survival rates

1. Life history table
2. Known fate approaches
   - Mark and relocate individuals
     - Collars on animals, relocate plants
   - Relocate individuals regularly/semi regularly
   - Record time to mortality or proportion of individuals alive




Methods for estimating survival rates

2. Known fate approaches
   – Average daily survival
   – Mayfield's estimator for daily nest survival:

$$\hat{S} = 1 - \frac{\#\ deaths}{Exposure\ days}$$

Deaths per exposure day

$$\hat{S} = 1 - \frac{\#\ deaths}{Exposure\ days\ - number\ censored\ animals}$$

Methods for estimating survival rates

2. Known fate approaches
   – Average daily survival (Trent and Rongstad 1974)

$$\hat{S} = \frac{x - y}{x}$$

$\hat{S}$ = estimate of the finite daily survival rate

x = total number of animal days observed over the period

(number of animals * observation days)

y = total number of deaths observed over the period

Methods for estimating survival rates

2. Known fate approaches
   – Average daily survival

Interval between relocation (day)	# animals relocated	# Survivors	# Deaths
1	47	45	2
2	23	22	1
3	36	33	3
4	12	12	0

$$\hat{S} = \frac{x - y}{x}$$

$$0.9759 = \frac{(47)(1) + (23)(2) + (36)(3) + (12)(4) - 6}{249}$$

Methods for estimating survival rates

2. Known fate approaches
   – Convert daily rates to other time interval:

$$\hat{p} = \hat{S}^{n} \quad \text{or} \quad Adjusted\ \hat{S}_0 = Observed\ \widehat{S}_0^{\ (t_s/t_0)}$$

p = estimate of finite survival rate per n days

$\hat{S}$ = estimated finite daily survival rate

n = number of days to upscale estimate

$$0.4810 = 0.9759^{30}$$

Methods for estimating survival rates Survival analysis

- Examines and models the time it take for events to occur
  - The event can be death, therefor “Survival analysis”

- Other names
  - “event-history analysis” : sociology
  - “failure-time analysis” : engineering

- Advantages:
  - Marked individuals checked on non-regular schedules
  - New left-censored individuals added to samples so that large n retained: “staggered entry design”
  - Accounts for right censored data – individuals lost to monitoring, but not assumed to have died
  - Right censored: unknown fate, radio failure or loss, emigration from study area.

Censoring: dealing with uncertain data

- Censored survival times:
  - problem when event has not occurred (within the observation time) or the exact time of event is not known.

- Right censoring:
  - Where the date of death is unknown but is after some known date
  - true survival time > observed survival time

e.g.

- Organism alive at end of the observation period (study)
- Subject is removed from the study
  - animal escapes, animal gets lost, plant gets eaten, etc.

Censoring

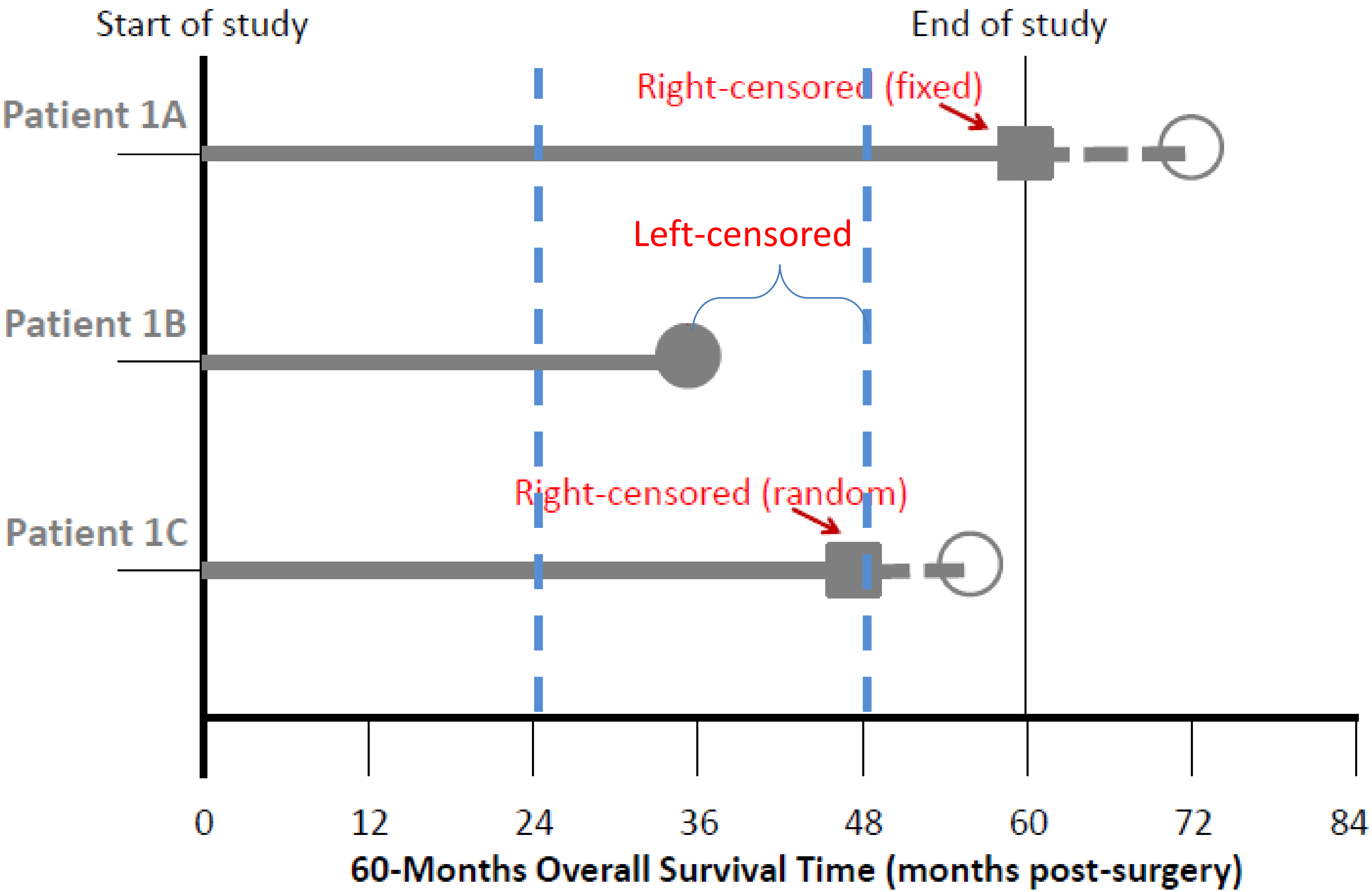
- Left censoring:
  - Occurs when a subject’s survival time is incomplete on the left side of the follow-up period.
  - True survival time < Observed survival time
  - Exact timing of event is uncertain: e.g..

e.g.

- We want to know time to death, but only assess survival when sampling

Censoring must be independent of the event being looked at

Censoring

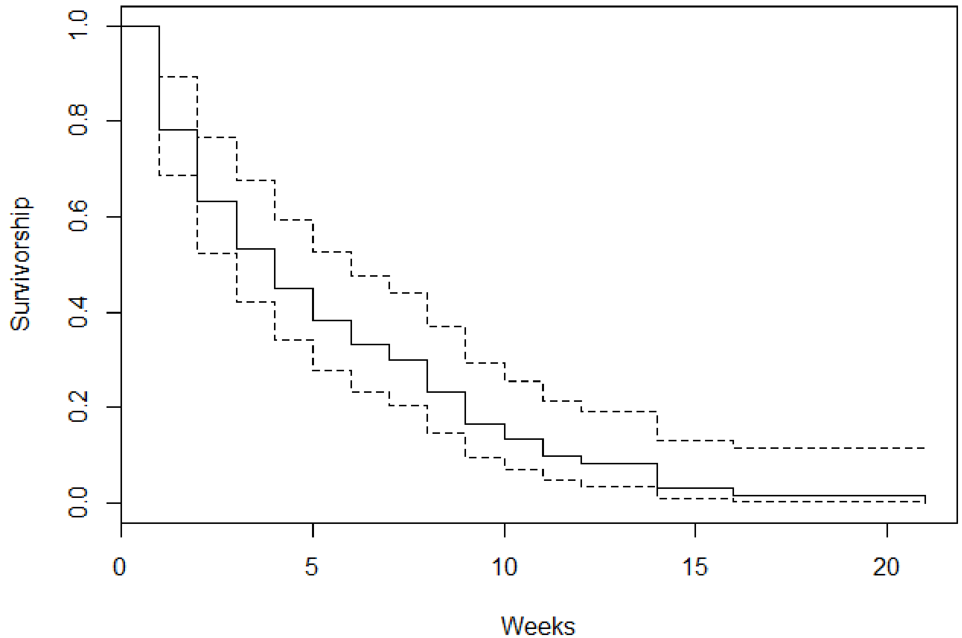


Start of study
End of study
Right-censored (fixed)
Patient 1A
Left-censored
Patient 1B
Right-censored (random)
Patient 1C
0
12
24
36
48
60
72
84
60-Months Overall Survival Time (months post-surgery)

Estimated/Empirical survival curves

- Survival curve is estimated by Kaplan-Meier (KM) estimator, also know as “product estimator”
- The Kaplan-Meier estimate is a nonparametric maximum likelihood estimate of the survival function, S(t)
- The estimate is a step function with jumps at observe event times

Kaplan-Meier estimate



events (deaths)

$$\hat{S}_{KM} = \prod_{t_i < t} \frac{r(t_i) - d(t_i)}{r(t_i)}$$

at risk

$$\hat{S}_{KM} = \prod_{t_i < t} \left[1 - \left(\frac{d(t_i)}{r(t_i)} \right) \right]$$

Kaplan-Meier estimate

$$\hat{S}_{KM} = \prod_{t_i<t} \left[1 - \left(\frac{d(t_i)}{r(t_i)} \right) \right]$$

Sample period	# birds with radios	# found dead	# censored	# added	Survival estimate
1	20	0	0	1	1
2	21	0	0	1	1
3	22	2	1	0	0.909
4	19	5	0	0	0.670

$$0.67 = \prod_{t_i<t} \left[\left(1 - \left(\frac{0}{20} \right) \right) \left(1 - \left(\frac{0}{21} \right) \right) \left(1 - \left(\frac{2}{22} \right) \right) \left(1 - \left(\frac{5}{19} \right) \right) \right]$$