Estimating Sea Lion Abundance from Aerial Surveys and Capture-Recapture Data

A work in progress

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How can we estimate Steller sea lion abundance?

Some history

- Calkins & Pitcher (1982) reconstruct age distribution to estimate total abundance
- Ratio pups : total $= 4.5$
- pup counts $\times$ 4.5 used ever since

What data to we have / can we get?

Capture-recapture

- Only mark pups
- Abundance estimation requires marking adults

What data to we have / can we get?

Areal surveys

- Pups counts reliable
- Nonpups are tricky [foraging or not present]

Overall goal

Want:

- N = Total number of wDPS sea lions in 2018
- Other abundance items, e.g., N_f = Total number of adult (4+) females

Have data:

- $\mathbf{C}$ = capture histories of pups marked since 2000
- $\mathbf{P}$ = pup counts at rookeries since 1986 (and before)

A Bayesian posterior predictive approach

Q: What do we know about nonpups?

A: They were once pups!

Notation (separate for each sex)

- P_y = number of pups observed in year y
- $N_{a,y}$ = Abundance of age a, individuals year y
- $S(t|s)$ = Survivorship to age t given alive at age s

Age-structured model

- $[N_{a,y}|P_{y-a}, S(\cdot|\cdot)] = Binom(P_{y-a}, S(a|0))$
- Note, no need for natality components!

Posterior distribution

Abundance

$$[\mathbf{N}_{2018}|\mathbf{P},\boldsymbol{\theta}] = \prod_{a=1}^{30} Binom(N_{a,2018}|P_{2018-a}, S_{\theta}(a|0))$$

Survival

$$[\boldsymbol{\theta}|\mathbf{C}] \propto CJS(\mathbf{C}|\boldsymbol{\theta}) \cdot [\boldsymbol{\theta}]$$

Bayesian predictive distribution

$$[\mathbf{N}_{2018}|\mathbf{P},\mathbf{C}] = \int [\mathbf{N}_{2018}|\mathbf{P},\boldsymbol{\theta}] \cdot [\boldsymbol{\theta}|\mathbf{C}] \; d\boldsymbol{\theta}$$

Ages-specific survival modeling

Survival analysis

Hazard function

$h(t)$, describes probability of death in a short age span, i.e.,
$P(\text{death } \in (t, t+\delta]) \approx h(t) \times \delta$
where $\delta \to 0$

Survival function

Probability of survival to age t given alive at age s:

$$S(t|s) = \exp\left\{-\int_s^t h(u)du\right\}$$
$$= exp\{-H(s,t)\}$$

Modeling hazard rate for Steller sea lions

$$h(t) = \alpha h_{juv}(t) + \eta h_{ad}(t) + \gamma$$

- α, η, γ are > 0.
- $h_{juv}(t)$ is a Weibull CDF
- $h_{ad}(t)$ increases exponentially
- γ is the baseline hazard

CJS Modeling

4 regions; 8 sites

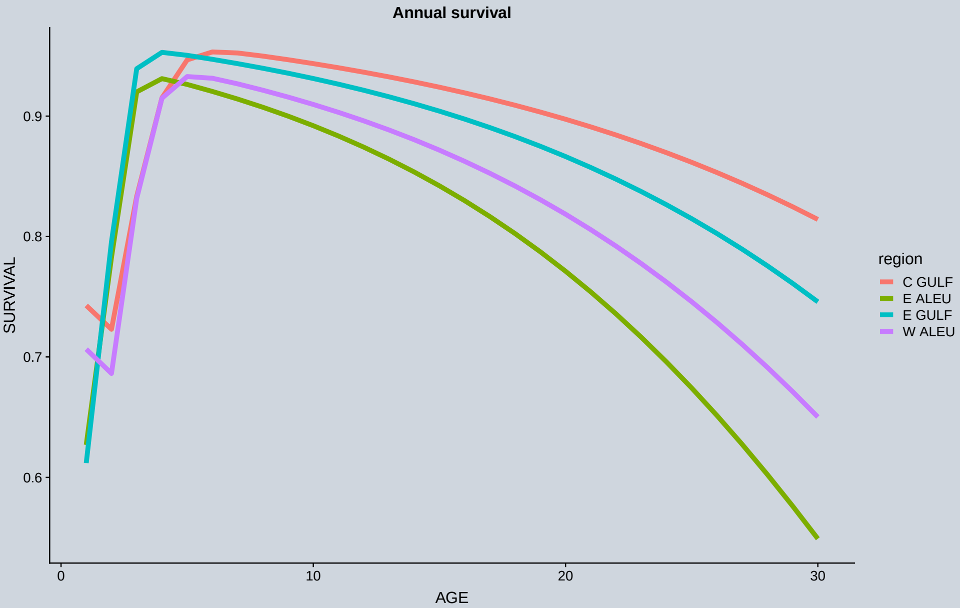
Survival parameters

- overall mean
- normal random effects for region
- variance components have exponential prior to induce sparsity

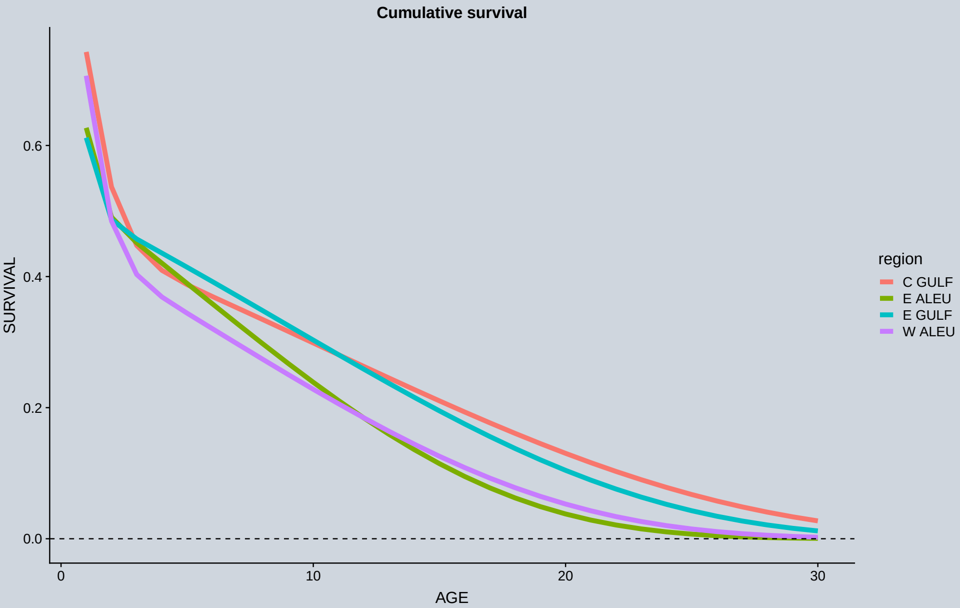
Detection parameters

- regional intercept
- site specific random effect
- site $\times$ occasion random effects
- exponential variance components

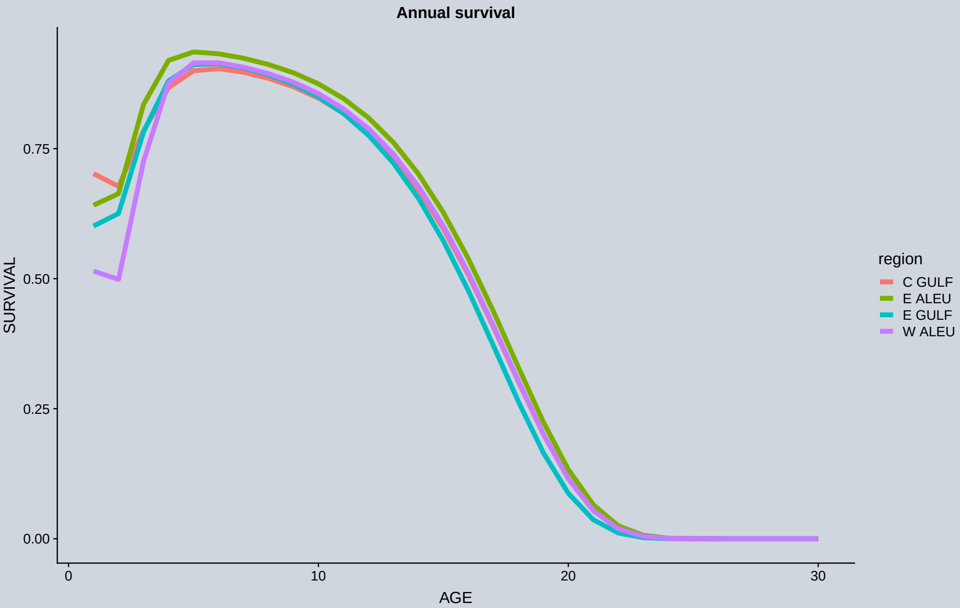
Survival results Female



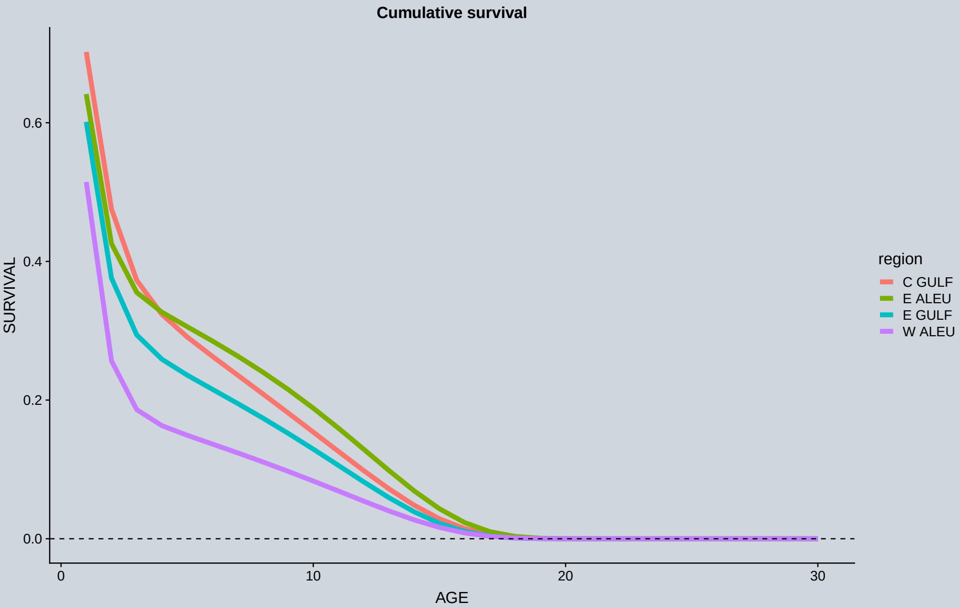
Survival results: Female



Survival results: Male



Survival results: Male



To do:
A pragmatic approach for abundance

Monte Carlo prediction of $N_{a,y}$

1. Fit CJS model to survival data and obtain MAP, $\hat{\boldsymbol{\theta}}$, and sample covariance, $\hat{\boldsymbol{\Sigma}}$
2. Approximate $[\boldsymbol{\theta}|\mathbf{C}] \approx N(\boldsymbol{\theta}|\hat{\boldsymbol{\theta}}, \hat{\boldsymbol{\Sigma}})$
3. For r in 1 to many
    1. Sample $\boldsymbol{\theta}^{(r)} \sim N(\boldsymbol{\theta}|\hat{\boldsymbol{\theta}}, \hat{\boldsymbol{\Sigma}})$
    2. Sample $\mathbf{P}^{(r)}$ using `agTrend` analysis
    3. Sample $\mathbf{N}_y^{(r)} \sim [\mathbf{N}_y|\mathbf{P}, \boldsymbol{\theta}^{(r)}]$
    4. Summarize quantity of interest, e.g., total abundance, $N_{2018}^{(r)} = \sum_{a=0}^{30} N_{a,2018}^{(r)}$

An earlier attempt

64,029 [61,093–66,943]