Demographic models

SSA 200

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Applications to SSAs

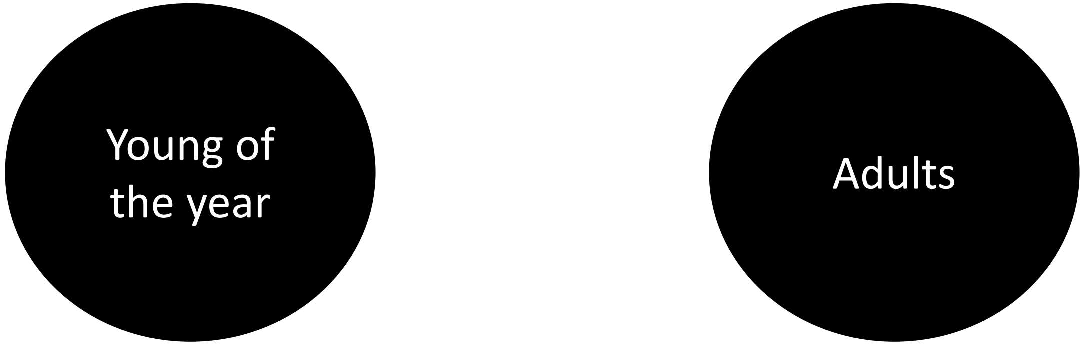
- Models are designed to output useful metrics on future resiliency and redundancy.
  - Metrics like future abundance, future extinction probability, future population growth rate
    - Output metrics are determined by available input data and what metrics will be most useful to decision makers
- Models allow us to predict future condition of the populations and characterize uncertainties in future condition.
  - We will focus on environmental variation and observation/parametric uncertainties

Lecture outline

- We will look at simple model construction
  - From conceptual to quantitative
- We will look at incorporating environmental covariates and density dependence
- We will look at parametric uncertainty

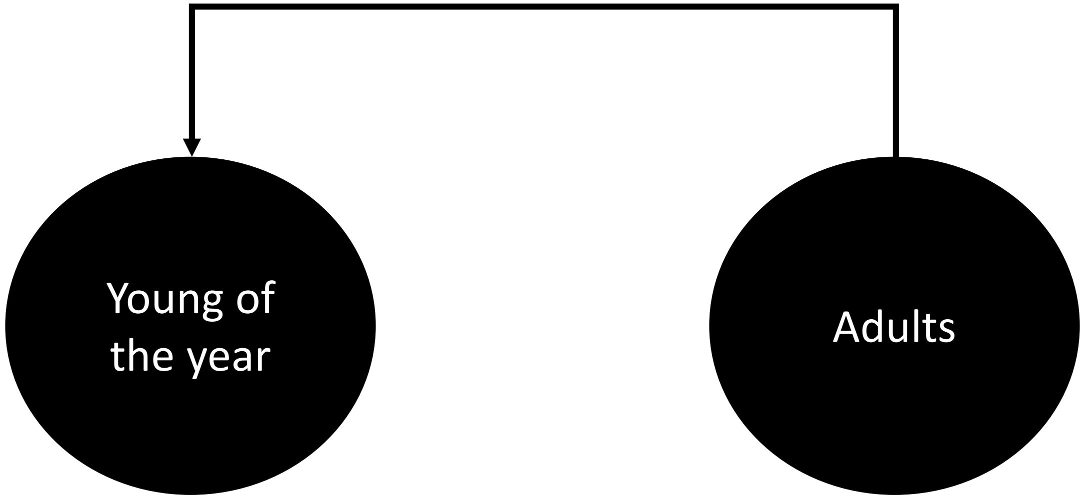
Conceptual model

- Two life stages
  - Adults
  - Young of the year



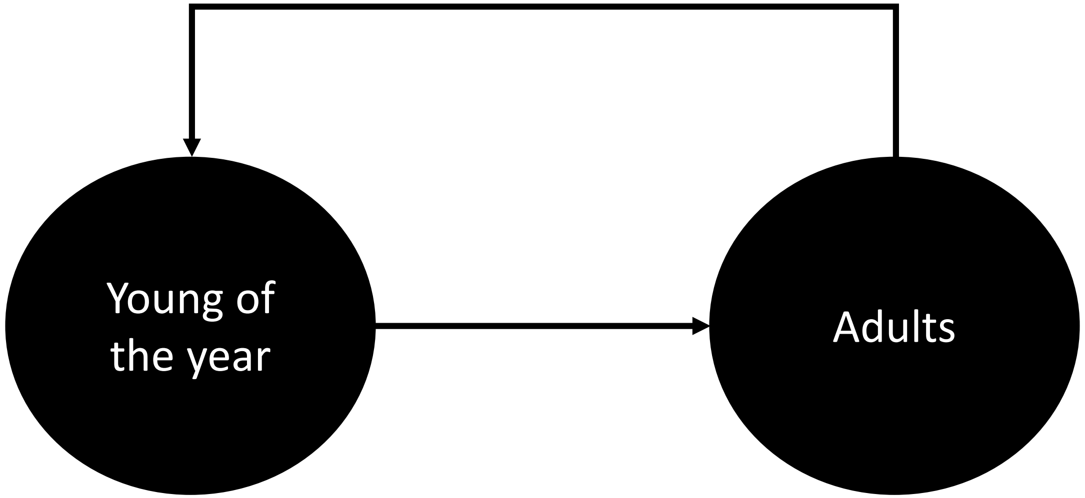
Conceptual model

- Adults reproduce



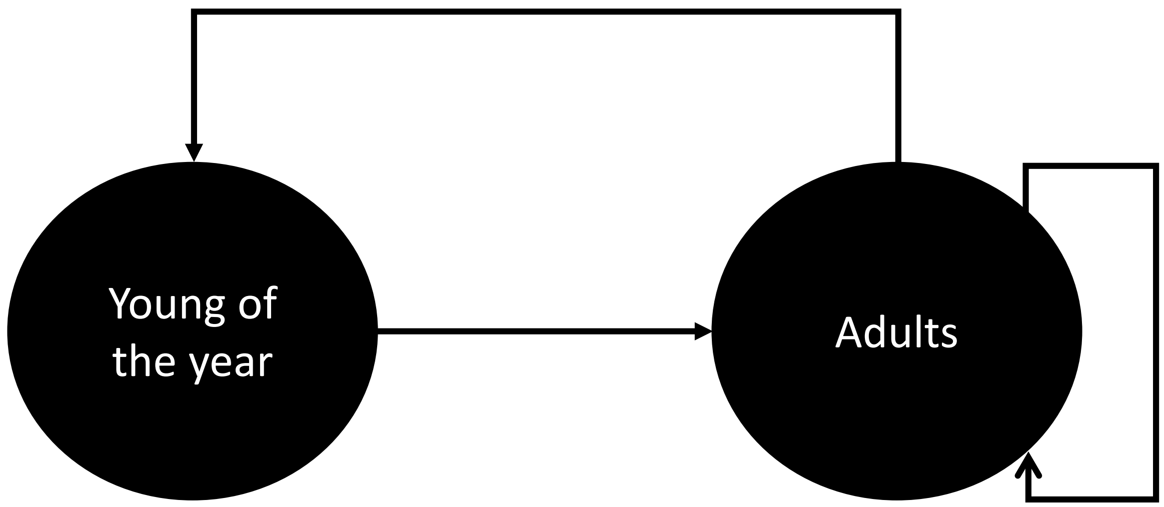
Conceptual model

- Young of the year survive and transition to adults



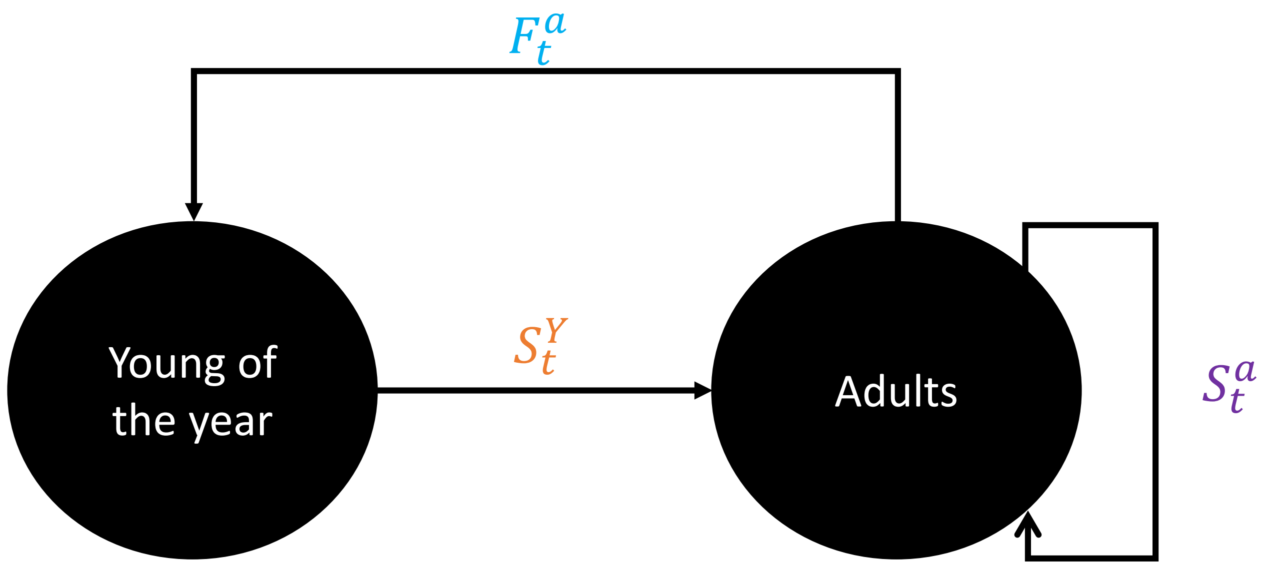
Conceptual model

- Adults survive and remain adults



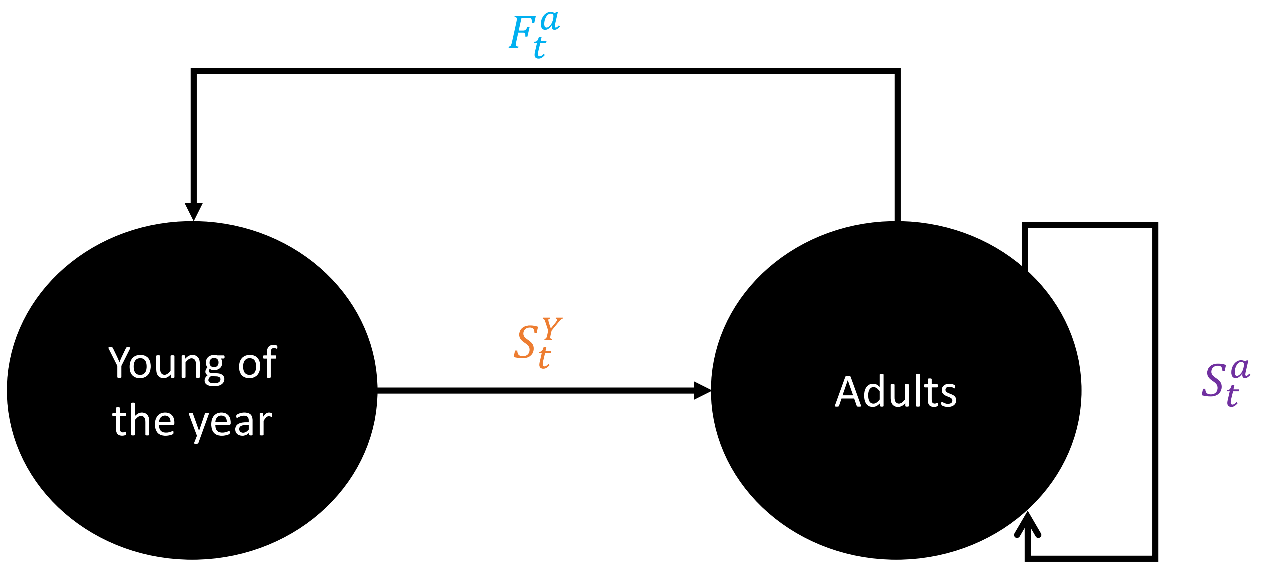
Quantitative model

$$N_{t+1}^{a} = N_t^a S_t^a + N_t^a F_t^a S_t^Y$$

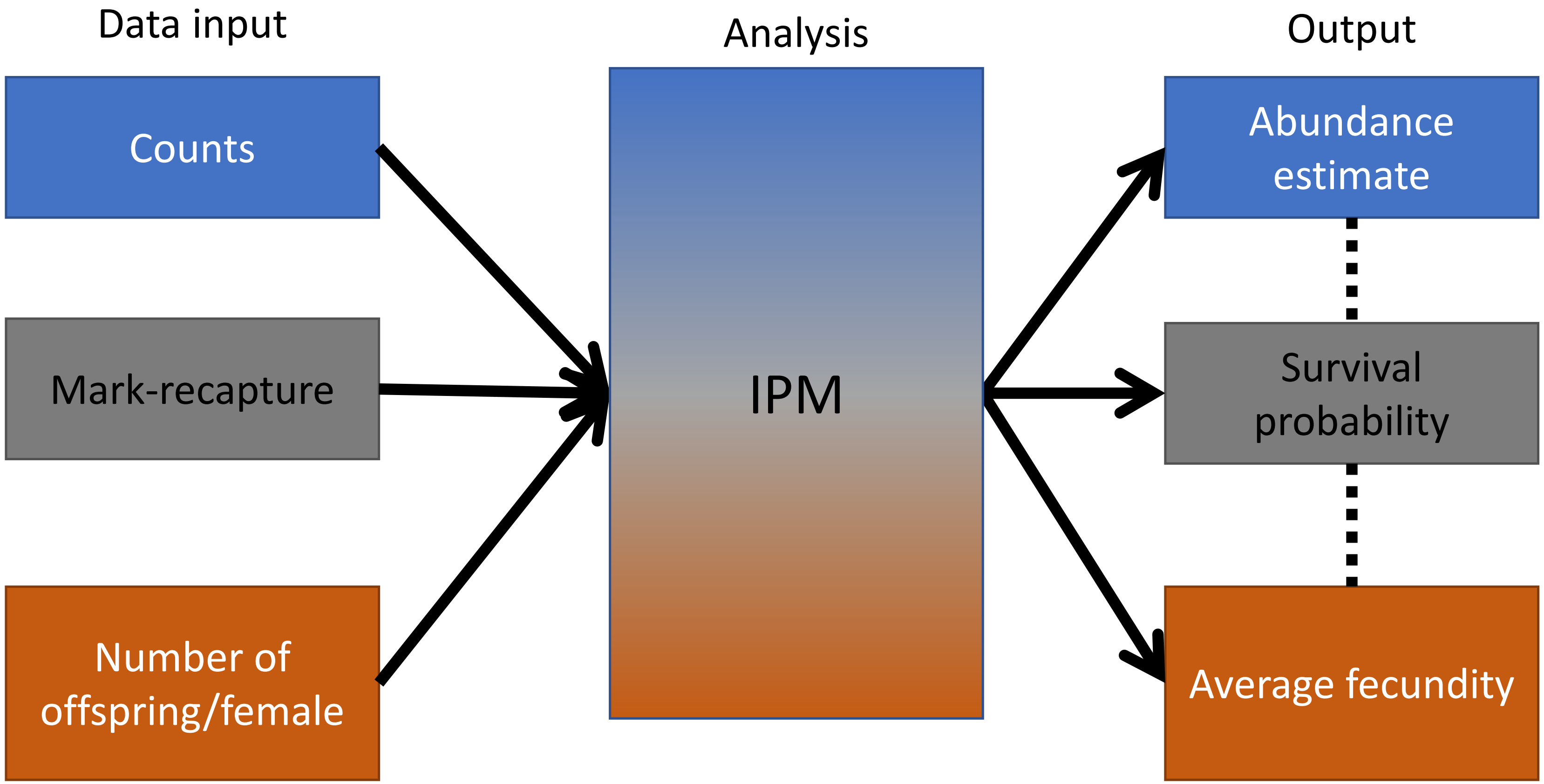


Matrix formulation

$$\begin{bmatrix} N_{t+1}^{Y} \\ N_{t+1}^{a} \end{bmatrix} = \begin{bmatrix} 0 & F_t^a \\ S_t^Y & S_t^a \end{bmatrix} \times \begin{bmatrix} N_t^Y \\ N_t^a \end{bmatrix}$$



Integrated population models



- IPM
  - Combine demographic data with counts
  - Use the model to make projections

Matrix projections

$$\begin{bmatrix} N_{t+1}^{Y} \\ N_{t+1}^{a} \end{bmatrix} = \begin{bmatrix} 0 & F_t^a \\ S_t^Y & S_t^a \end{bmatrix} \times \begin{bmatrix} N_t^Y \\ N_t^a \end{bmatrix}$$

$$N_{t+1} = \mathrm{A} * N_t \quad \longleftrightarrow \quad N_{t+1} = \lambda * N_t$$

Sensitivity and elasticity

$$\begin{bmatrix} N_{t+1}^{Y} \\ N_{t+1}^{A} \end{bmatrix} = \begin{bmatrix} f_{1,1} & f_{1,2} \\ s_{2,1} & s_{2,2} \end{bmatrix} \times \begin{bmatrix} N_{t}^{Y} \\ N_{t}^{A} \end{bmatrix}$$

$$Sensitivity = \frac{\delta\lambda}{\delta s_{2,2}}$$

$$Elasticity = \frac{s_{2,2}}{\lambda}\frac{\delta\lambda}{\delta s_{2,2}}$$

Sensitivity is the rate of change in population growth (λ) with respect to a change in any element of the matrix.

Elasticity analysis estimates the effect of a **proportional** change in the demographic rates on population growth (λ).

How to estimate sensitivity and elasticity

- **Program R – Package 'PopBio'**

Population matrix → $\begin{bmatrix} 0 & F_t^A \\ S_t^Y & S_t^A \end{bmatrix}$ → $\begin{bmatrix} 0 & 1.2 \\ 0.3 & 0.8 \end{bmatrix}$

Sensitivity matrix → $\begin{bmatrix} 0.222 & 0.208 \\ 0.832 & 0.777 \end{bmatrix}$

Elasticity matrix → $\begin{bmatrix} 0 & 0.222 \\ 0.222 & 0.554 \end{bmatrix}$

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Simple future condition assessments

- Using sensitivity and/or elasticity output
  - Results indicate population growth is most sensitive to adult survival
    - Conceptual modeling and literature review suggest that adult survival is negatively affected by drought frequency
    - Climate change predictions suggest that drought frequency will increase over the next 50 years
  - We therefore expect adult survival to decrease and in turn population growth will decrease
  - We conclude that if climate predictions are accurate, future resiliency will decrease

Forms of uncertainty

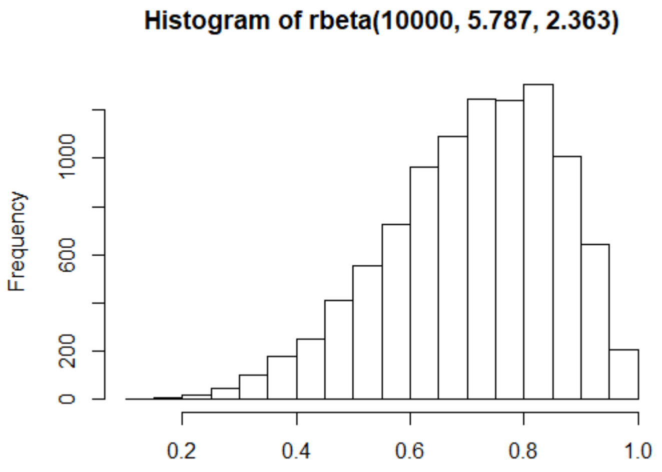
- Partial controllability
- Observational uncertainty
- Environmental variation
- Ecological uncertainty
- Demographic stochasticity

Incorporating uncertainty

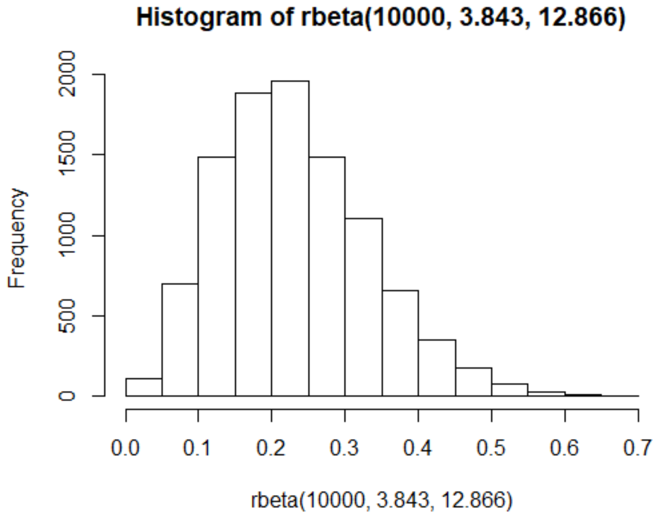
- Environmental stochasticity
  - Survival parameters typically drawn from a beta distribution
    - Convert estimated mean and variance to beta shape parameters
      - Continuous but restricted between 0 and 1
      - Really useful to species with high or low survival
  - Productivity parameters have two typical methods
    - Log-normal, bounded by 0 and infinity
      - Convert estimated mean and variance to log-normal distribution
    - Poisson distribution summed over all the individuals in the population

Survival rates

- S = 0.71, S.D. = 0.15 → Beta1 =5.787 Beta2 =2.363 →

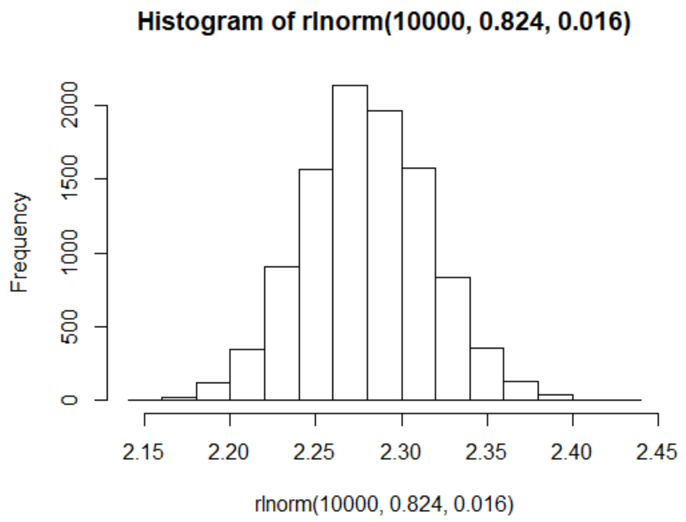


- S = 0.23, S.D. = 0.1 → Beta1 =3.843 Beta2 =12.866 →

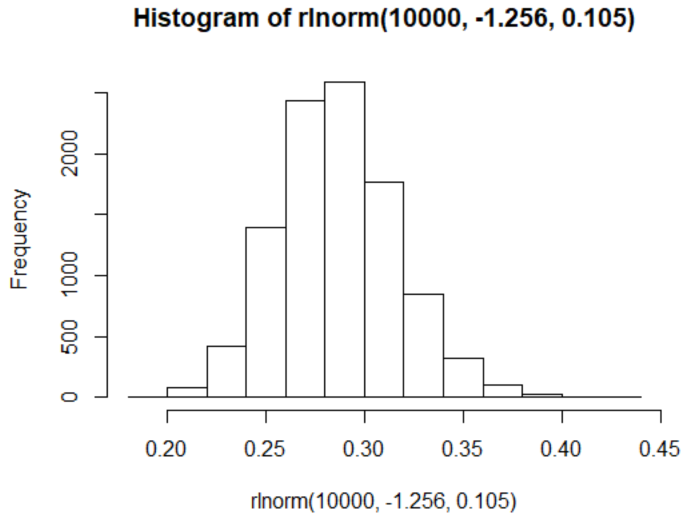


Productivity rates

- F = 2.3, S.d. = 0.3 → S1= 0.824, S2 = 0.016 →



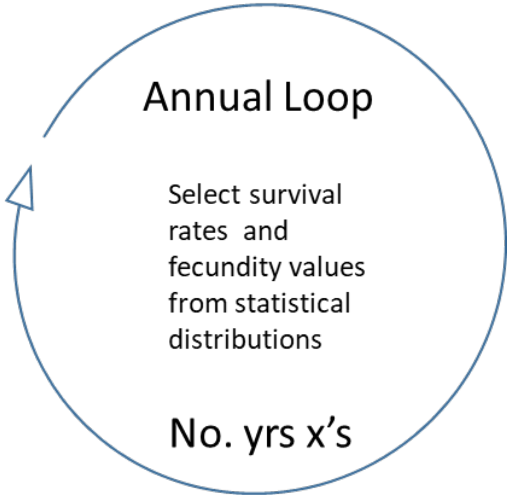
- F = 0.3, S.d. = 0.1 → S1= -1.256, S2 = 0.105 →



For loops in simulation models

- Programmers utilize loop functions that tell a program to execute the following set of functions over and over again a specified number of times:

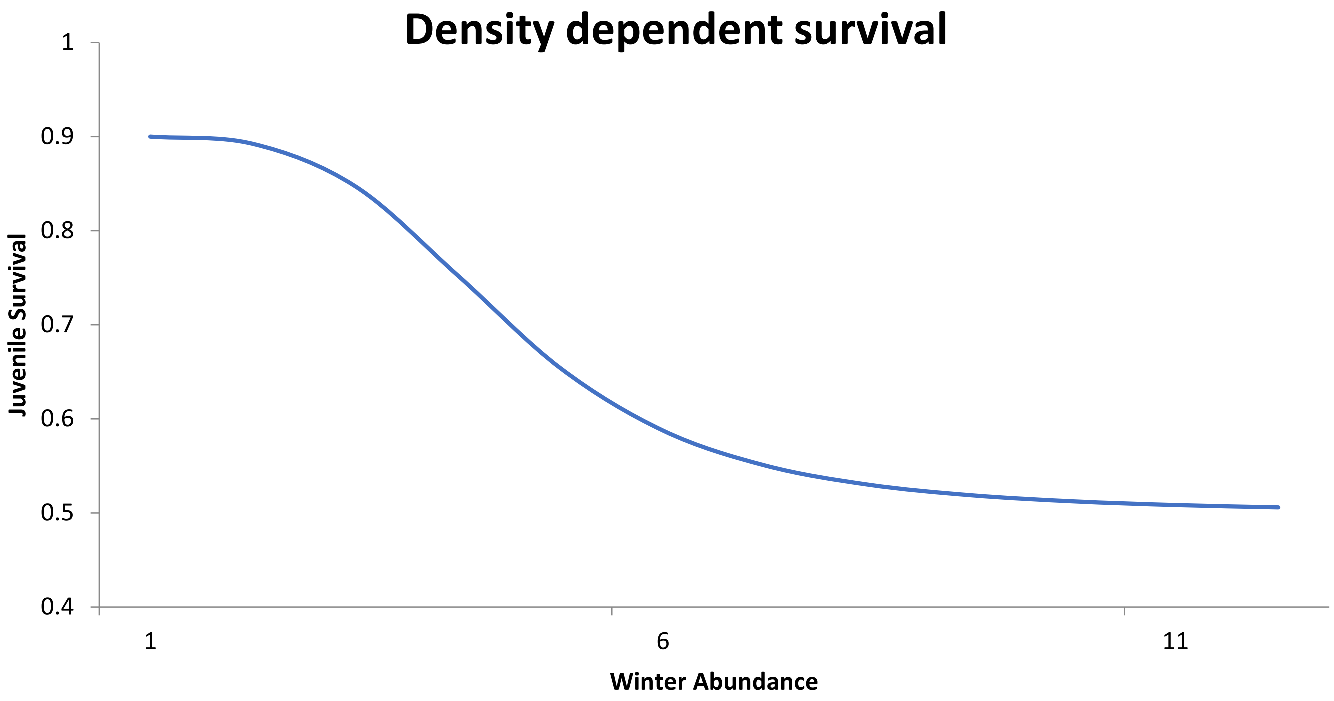
```
for(i in 1:1000){
#Tells the computer to repeat a function
#1000 times
}
```



- With in those loops we can choose randomized parameter values and project populations
  - Typically use 2 loops to project time and replicate the simulations

Density dependence

- Model parameters are a function of population density



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Applying density dependence

- Incorporated a density dependent function on juvenile survival

$$N_{t+1} = N_t F_{A,t} S_{j,t} + N_t S_{a,t}$$

$$S_{j,t} = \frac{exp\left(\alpha - \beta\left(N_t + N_t F_{A,t}\right)\right)}{1 + \left(\exp\left(\alpha - \beta\left(N_t + N_t F_{A,t}\right)\right)\right)}$$

Ceiling type density dependence

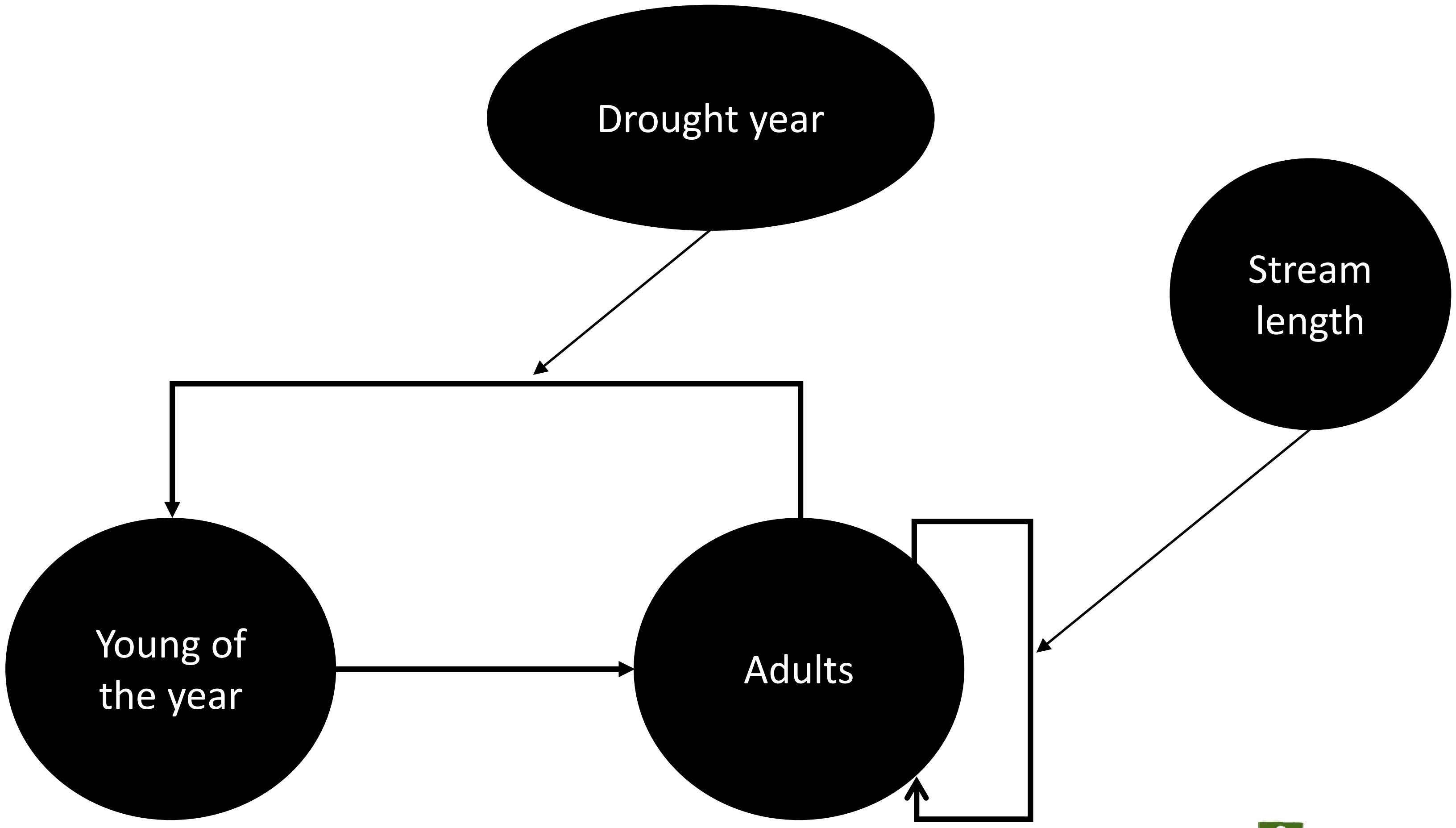
Threshold Density dependence

- "If the population exceeds a ceiling threshold, fecundity is equal to zero"
- if (n[i,j] > ncrit) F[i,j] = 0

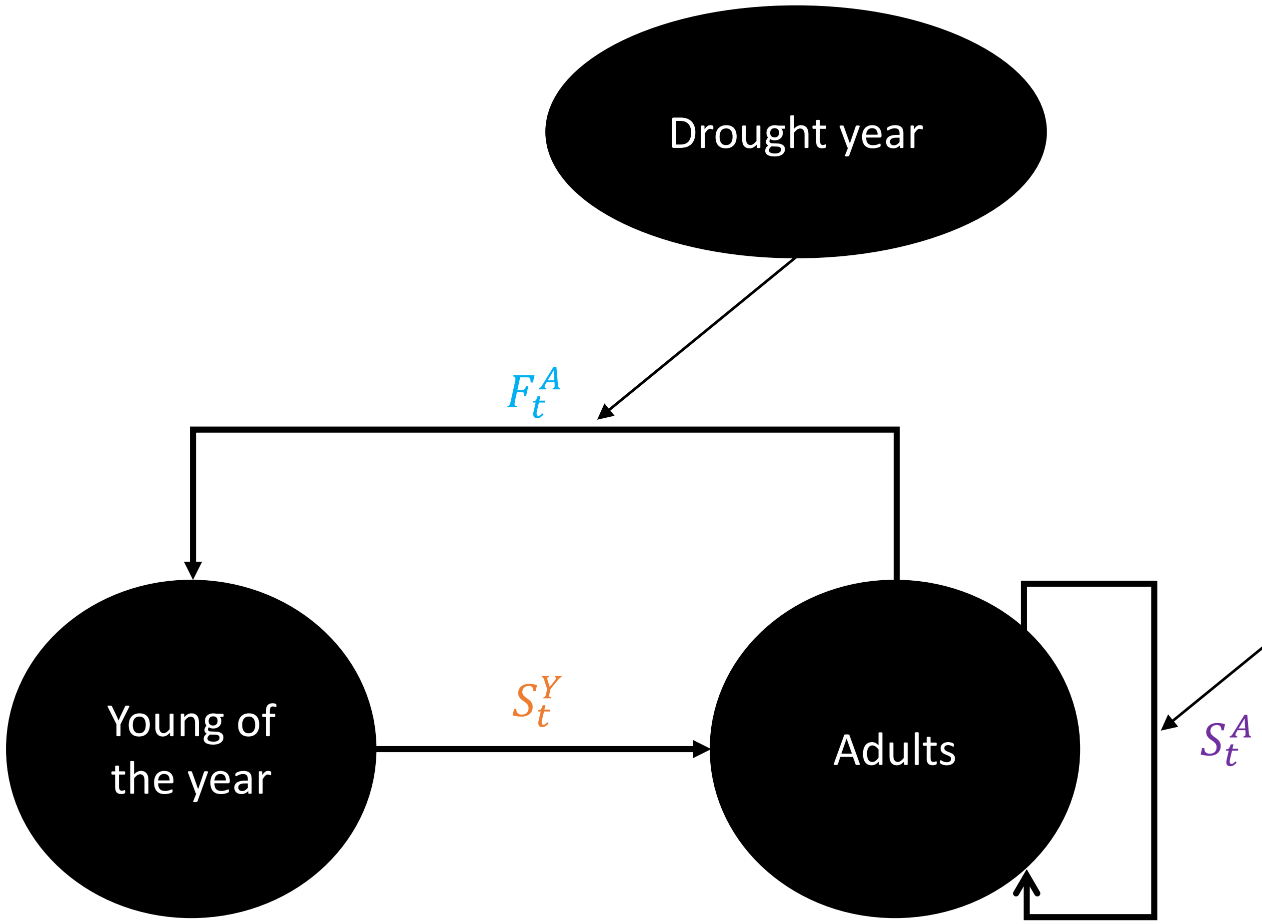
Or

- "As the population approaches some ceiling threshold, fecundity gets smaller and smaller"
- F[i,j]= F[i,j]*(1-n[i,j]/ncrit)

Conceptual models environmental effects



Quantitative model



Environmental covariates

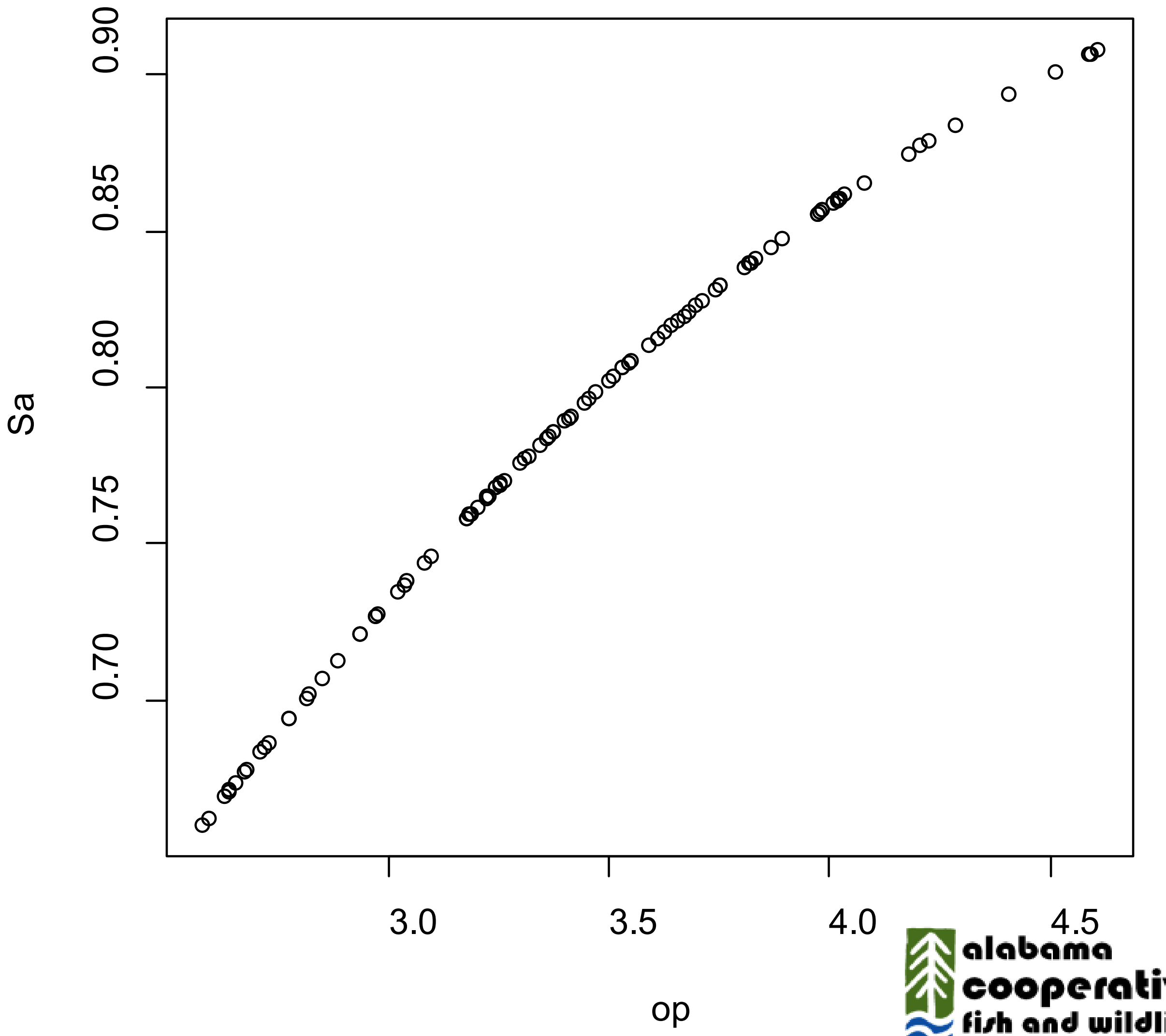
- Conditionally linked events:
  - Use “If→then” statements to link a demographic parameter to some other randomized event
    - E.g., if a Bernoulli trial for drought returns a 1, then mean fecundity is 1.1 offspring per female, but if it returns a 0 then mean fecundity is 2.3 offspring per female

Logit link for population parameters

- Based on logit link functions
- Correlation parameter estimates from survival estimates or occupancy analyses are on the logit scale
  - You can use the logit function to predict the survival rate for any give value of the measured covariates

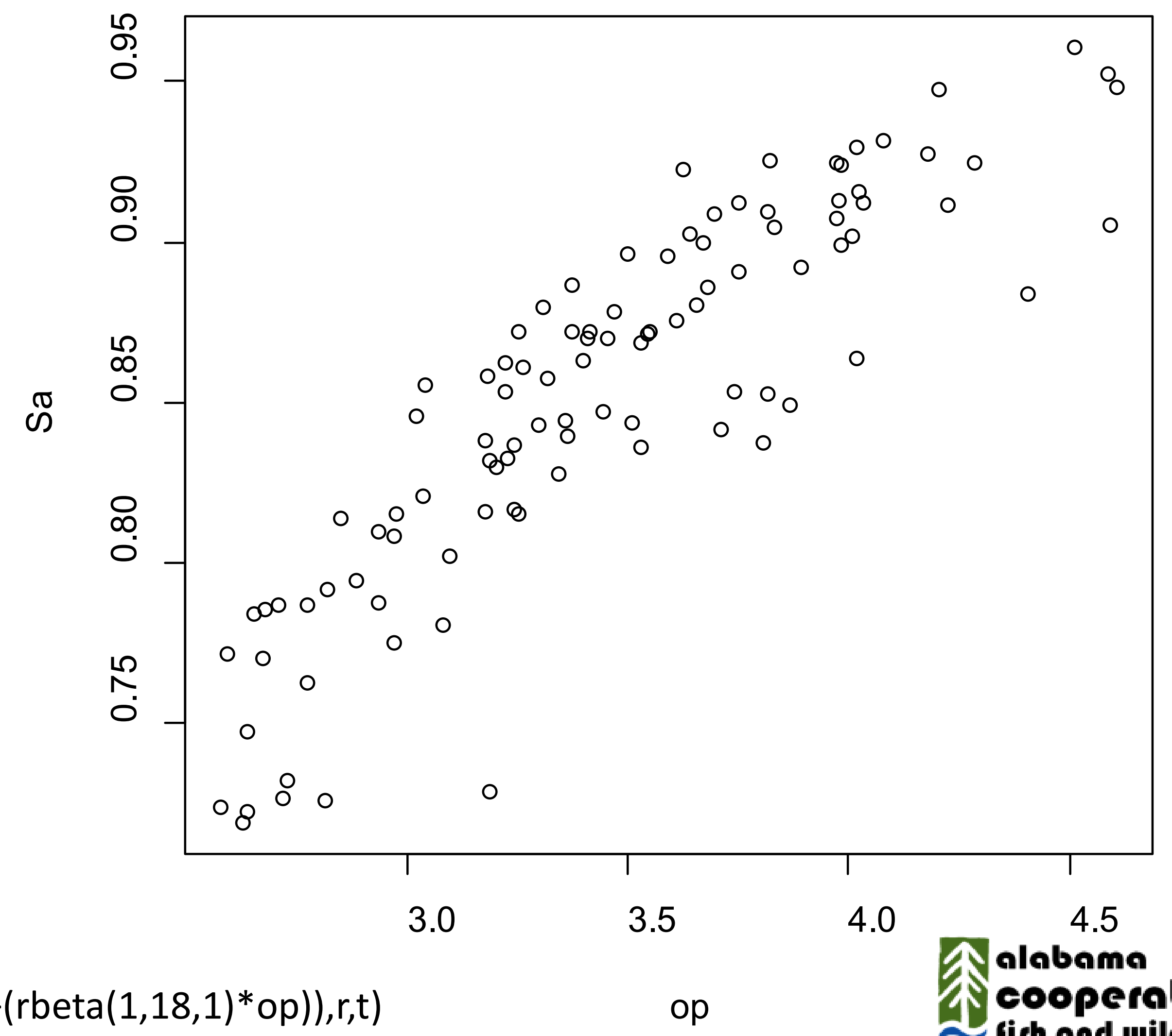
Environmental covariates

- Adult survival (Sa) can be a function of some other environmental parameter/variable
    - ("op" for other parameter, e.g., stream length)



Environmental covariates

- Adult survival (Sa) can be a function of “op” but it has variability



Sa=matrix(plogis(-rnorm(1,1.4,.1)+(rbeta(1,18,1)*op)),r,t)

Parametric uncertainty

- Parameters values are not precisely known
  - Variance or standard deviation estimates for parameters estimated over years conflate environmental variation with sampling variance
  - Sampling variance is the result of only using a specific number of individuals or locations to study a phenomenon
    - Happens with every wildlife study because we can't study every individual in every location

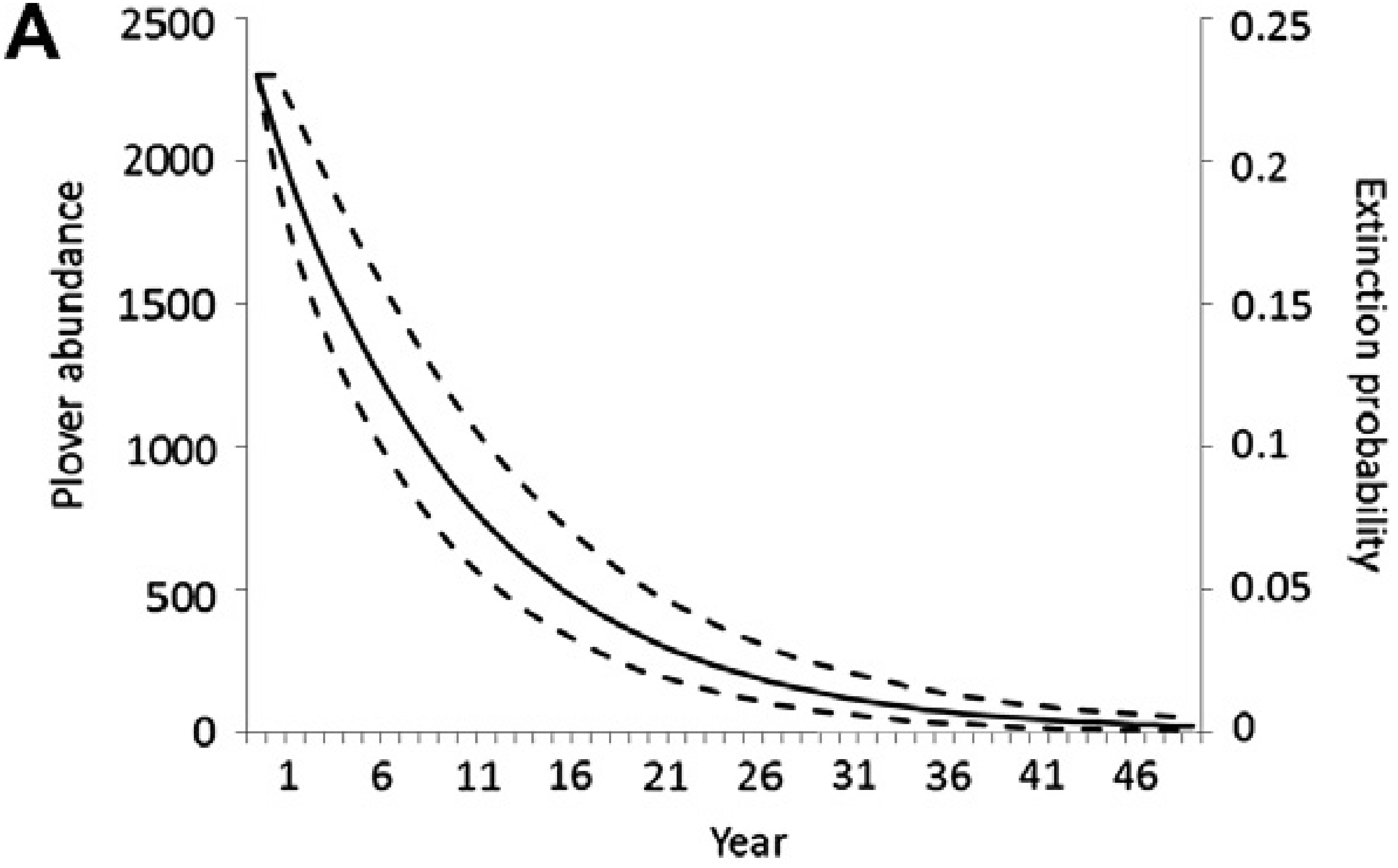
Methods to partition variance

- Link and Nichols, 1994, Oikos
- Gould and Nichols, 1998, Ecology
- $S^2 = \frac{1}{n-1}\sum_{i=1}^{n}\left(\hat{A}_i - \hat{\bar{A}}\right)^2$
- $\hat{\tau}^2 = S^2 - \frac{1}{n}\sum_{i=1}^{n}\left[Var\left(\hat{A}_i\right)\right]$

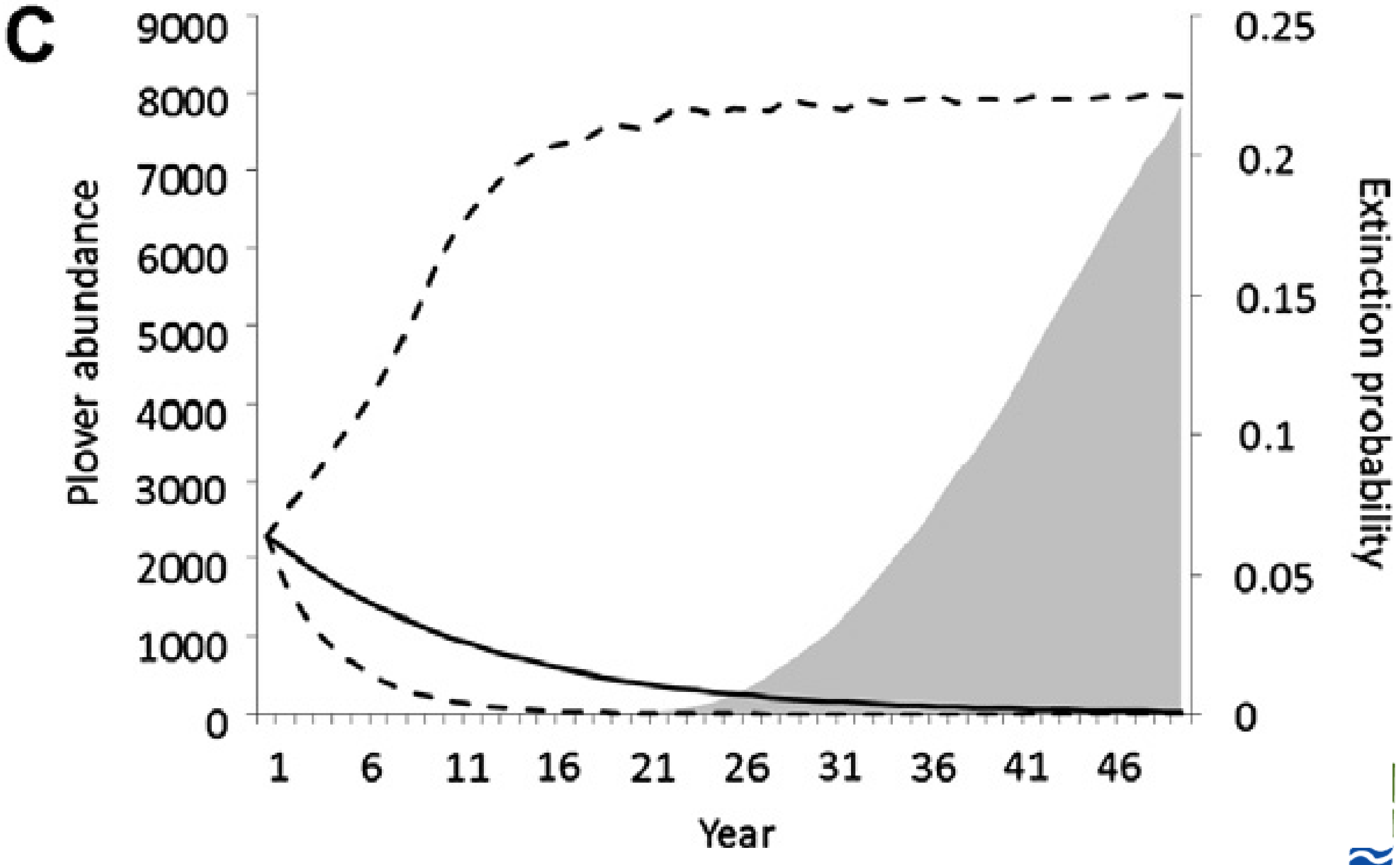
Great, so what do we do about it?

- Most models will discard sampling variance
- Not always a good idea!
  - Pretending that we know system parameters with precision
    - Less variation in the model predictions
    - Could affect assessment of management choices

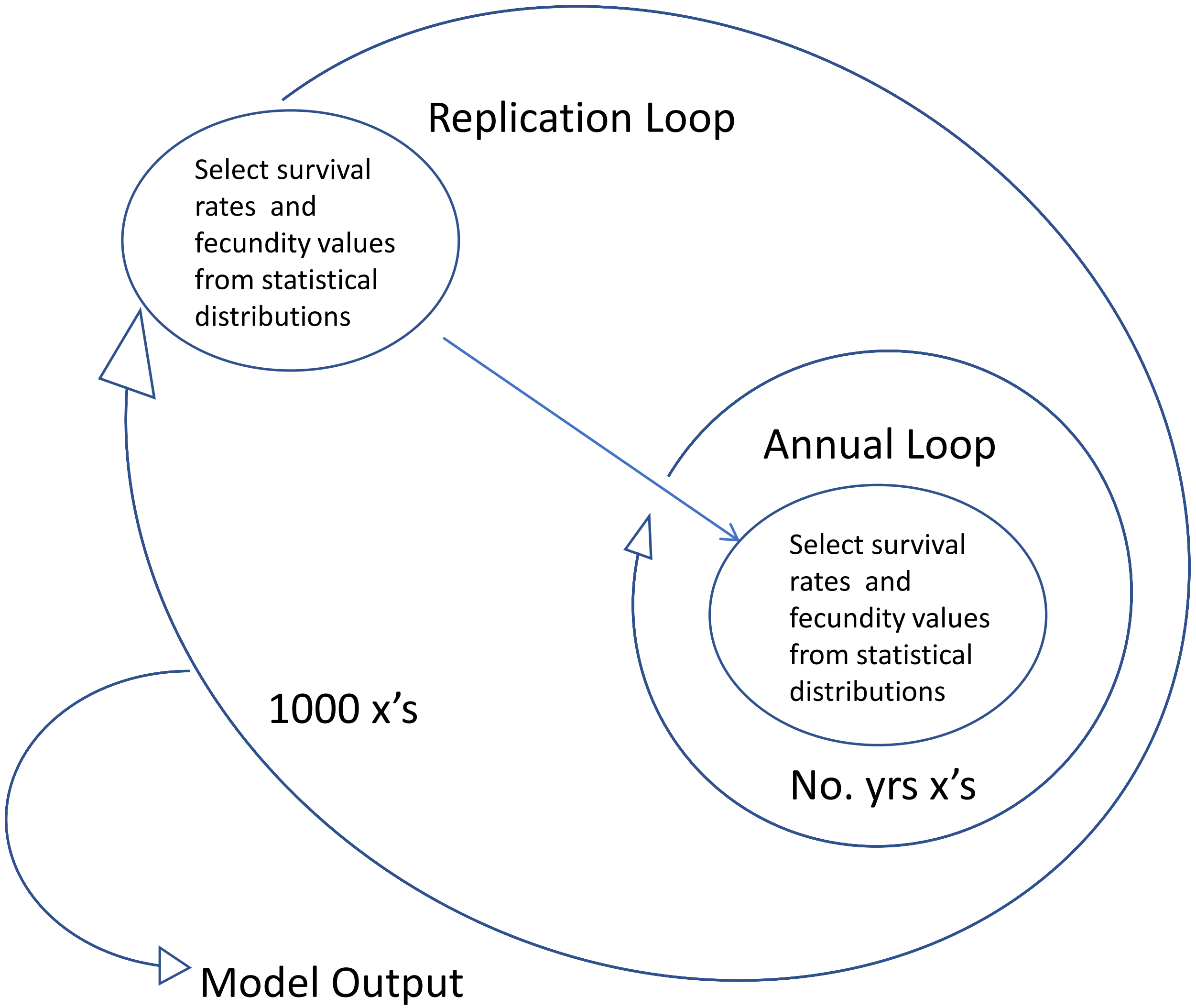
Projection without sampling variance



Projection with sampling variance

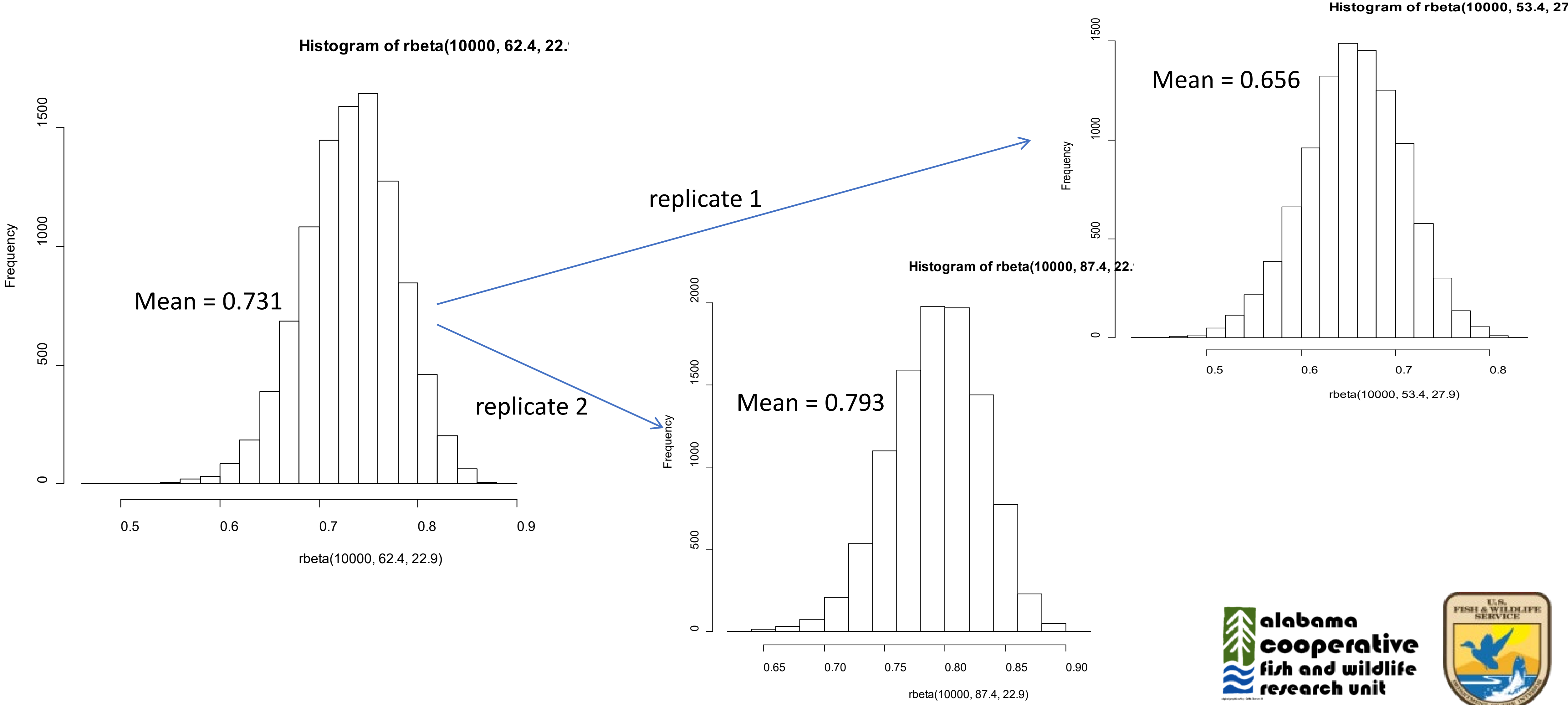


How do we model these uncertainties?



Hierarchical loop structure: parametric and environmental uncertainty

Modeling uncertainty in adult survival



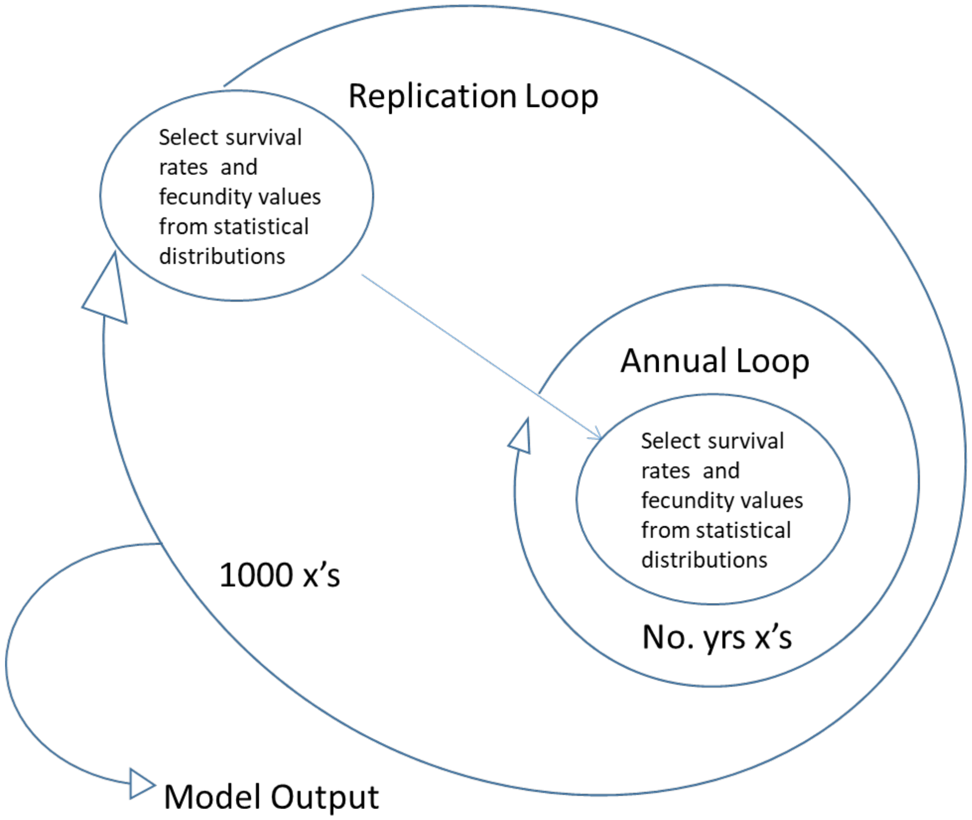
Double for loops

- for(i in 1:1000){
  - #Select mean parameter values a replicate
- for(j in 1:50){
  - #Select values for each year until you reach 50 years then move on to
  - #the next replicate

}

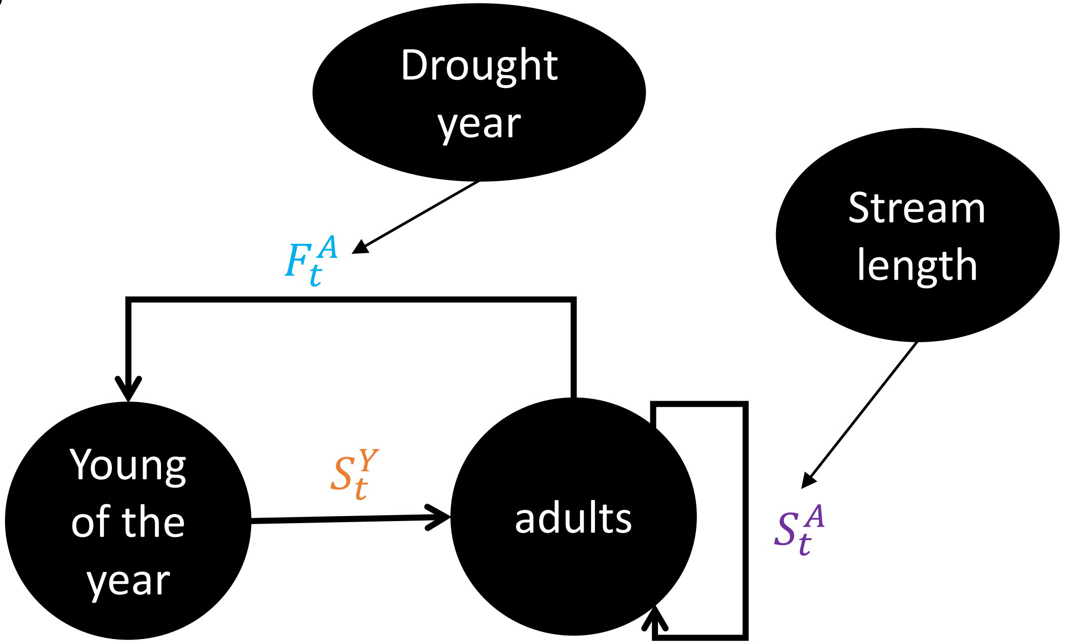
  - #save and summarize output from a replicate until you reach 1000 #replicates

}



Inputting scenarios

- Use the conceptual model and sensitivity analysis to guide scenarios
  - i.e., what ecological facts affect the most sensitive parameters?
- Design scenarios to explore the expected range of future variation in important covariates



Using this structure to build GLMs

- Generate lots of output values (e.g. abundance, p(ex), etc.) with lots of corresponding input values
- Use a multi-variate GLM to assess the importance of each variable of interest:
    - $p(extinction) \sim b_1(Initial\ N) + b_2(drought\ freq) + b_3(fecundity)$ …
    - This is a binomial GLM

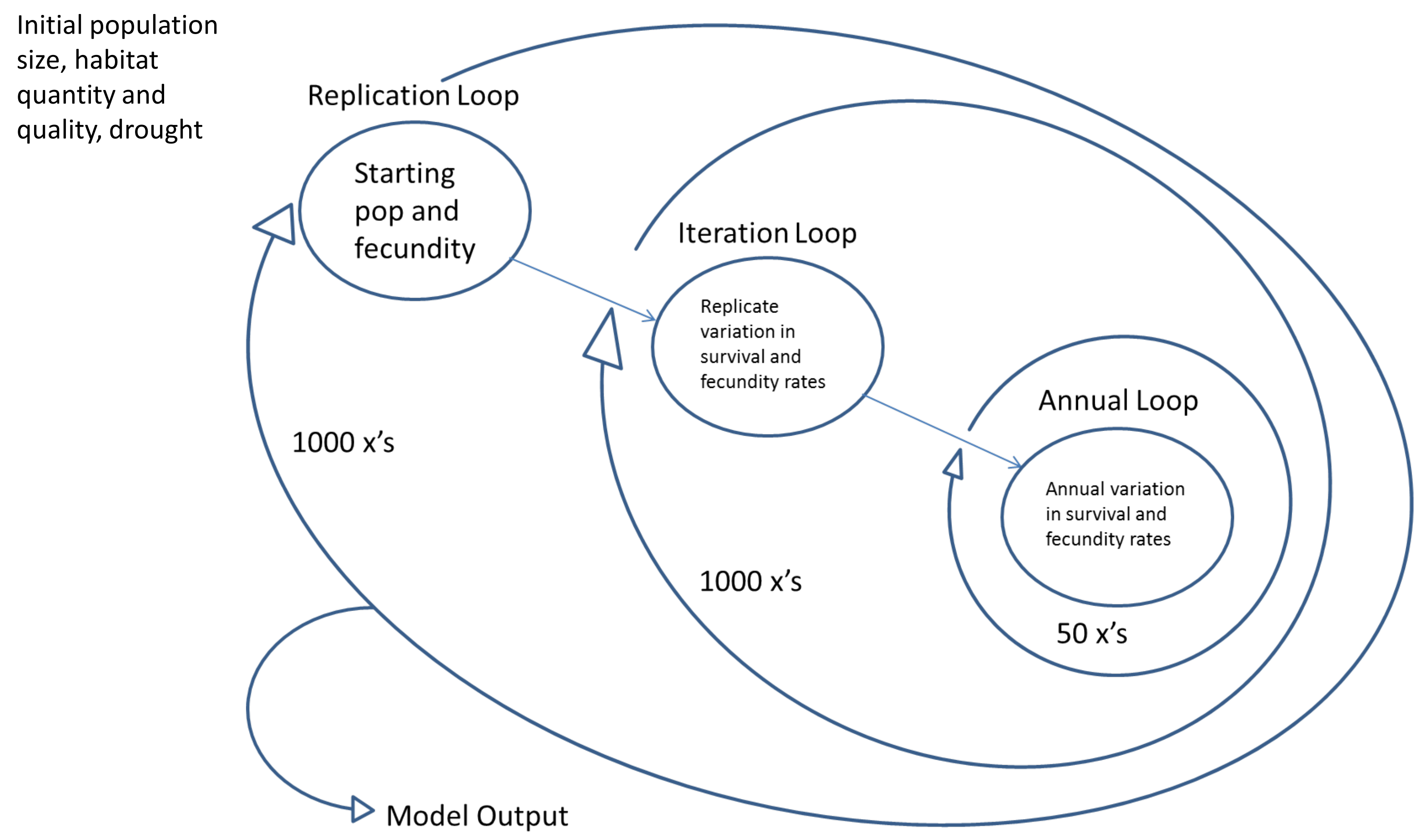
- What factors most effect the output metric of interest?

Sonora desert tortoise example

- $P(Qe100) =– 5.602 + (18.42\ x\ MDR) – (5.363e – 6x\ NAI) – (1.797e – 6x\ MaxPop)$

- MDR = mean drought rate
- NAI = Initial Number of adults
- MaxPop = habitat based maximum population size
    - You could input different values of MDR, NAI or MaxPop to predict the corresponding P(Qe100), i.e., input alternative future scenarios.

Hierarchical loop structure



Incorporating posterior observation uncertainty

- What we observe will differ from model predictions
- Could be an issue for recovery planning or delisting decisions
- Use estimates of detectability to adjust abundance outputs
  - Estimates of detection from empirical studies
    - Literature, directed research for the SSA
    - $N_t^{Obs} = N_t^{Act} \times E_t$

Where *E* is the counting error

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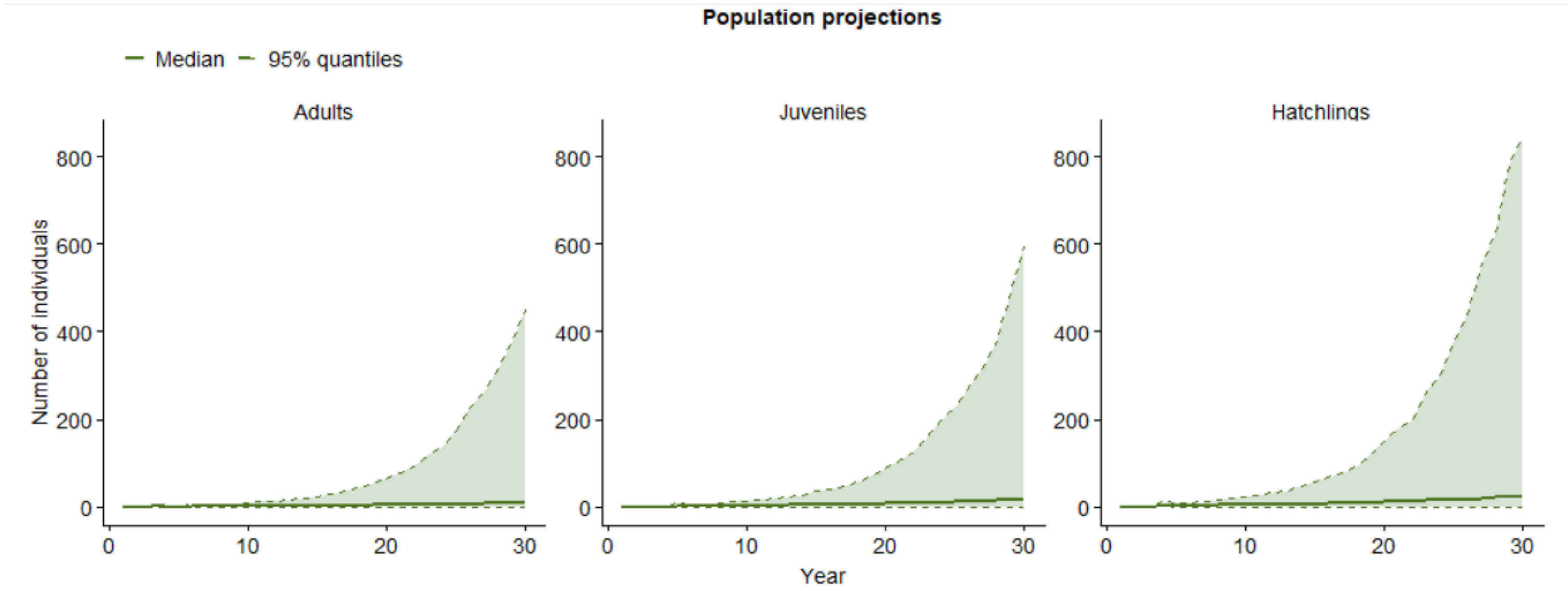
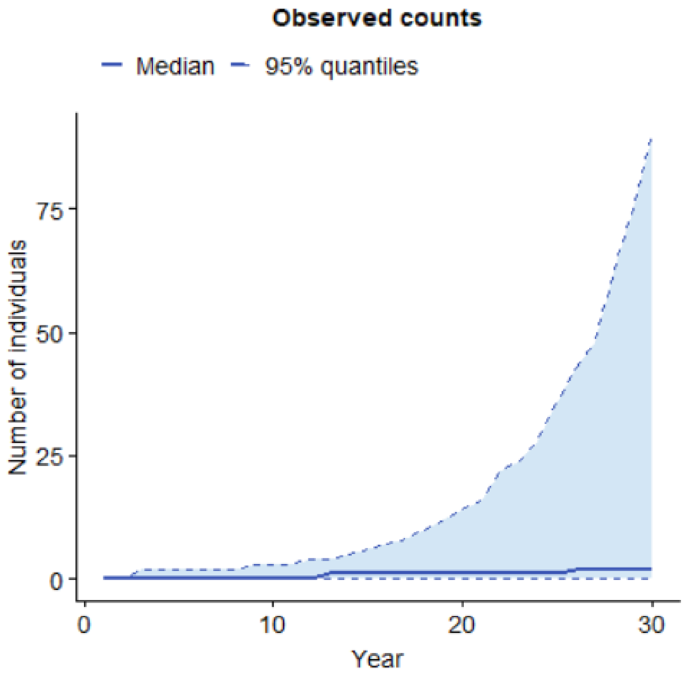


Abundance projections



True lambda	Observed lambda	Extinction probability
1.06	0.70	0.39

Expected counts

Questions?