Lecture 23 Use of Mechanistic Models Combined with Estimates from Field Studies

Examples

- Golden Eagle Popn near a Wind Farm
- Influence of Dam Removal on Salmon
- Manatee Populations in Florida (Boat Accidents)
- Sea Turtles (Fishing Bycatch and TEDS)
- Effects of Hunting on Turkey Popns
- Fisheries Stock Assessments

Sampling Issues for the Field Based Estimates

Graded Draft Proposals Return

- Returned today or this Thursday at class.
- Drafts were graded out of 15 with the final proposal also to be graded out of 15. Please talk to me if you are unclear about any points and try to make the improvements I suggest
- If the proposal was very advanced and good then I graded it as a final proposal and will not need to see it again. There were such a range of stages of students that this approach could be adopted.
- I tried to give as many helpful suggestions as I could.

Graded Draft Proposals

- Based on those I have read so far.
- Students research was generally integrative with multiple studies involved. Students sometimes used expts or quasi expts to augment their observational data.
- Sometimes sample sizes were very small due to practical limitations of various kinds. Sometimes advisors or students appear to have obtained grants without sufficient funds for the studies ideal implementation.
- Students were generally very conscientious about discussing model assumptions of their various sampling methods.

Reminders-Guest Lectures

- This Thursday Tom Wentworth, a plant ecologist. He will emphasise sampling and the use of multivariate cluster analysis to look for relationships. Lecture and a paper already on the website.
- The following Thursday Rob Dunn on examples of meta analysis. Combining multiple studies to solve “very large problems”. An important paper is on the website already.

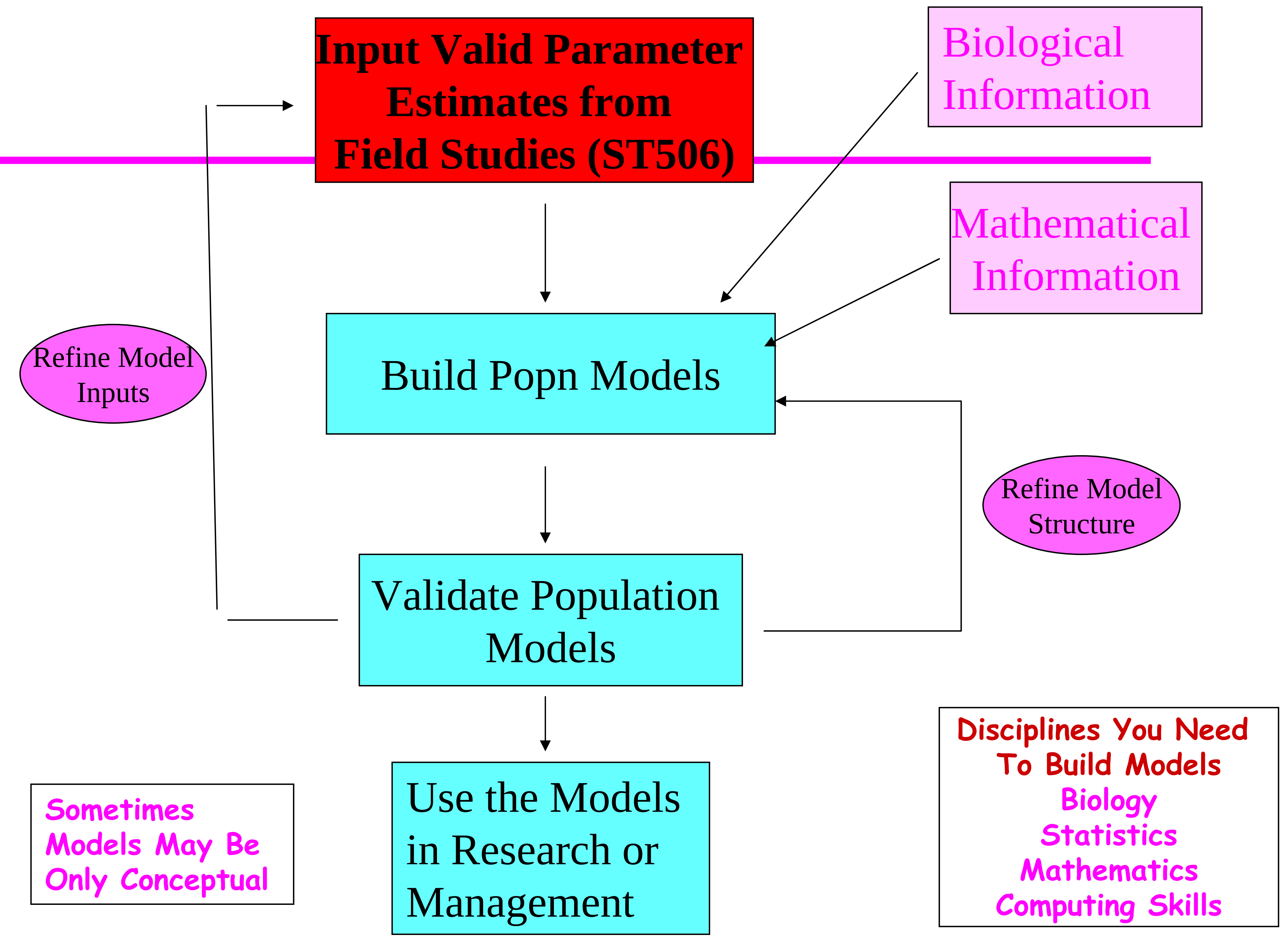
MECHANISTIC MODELS FOR LARGE SCALE ECOLOGICAL STUDIES

- Many large scale ecological studies where the goal is to test some hypothesis or hypotheses but where one cannot use randomization, or any replication of control or treated sites.

- Therefore, despite advantages of traditional statistical approaches based on experiments or their weaker relations like BACI designs, the use of mechanistic model based inference in combination with field sampling sometimes may be the only viable option.

- Weaknesses of modeling approach obviously are the possibility of invalid model assumptions and use of biased or imprecise estimates of input parameters from field studies or worse only informed guesses.

- Examples are the dam removal study, golden eagle wind farm study, hunting effects on populations, fishing effects on populations, manatee popns in Florida


Input Valid Parameter Estimates from Field Studies (ST506)
Biological Information
Mathematical Information
Build Popn Models
Refine Model Inputs
Refine Model Structure
Validate Population Models
Use the Models in Research or Management
Sometimes Models May Be Only Conceptual
Disciplines You Need To Build Models
Biology
Statistics
Mathematics
Computing Skills

MECHANISTIC MODELS FOR LARGE SCALE ECOLOGICAL STUDIES

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Many Examples of this Approach

- Golden Eagle Population near a Windfarm in CA.
- Effects of Dams on Chinook Salmon
- Sea Turtles and Bycatch (Use of TEDS)
- Manatee Popn Model (Influence of human related threats such as boating accidents)
- Hunting Effects on Exploited Popns
- Fisheries Stock Assessments

Golden Eagle Example

- Threatened species status under the U.S. Endangered Species Legislation
- There is a large population of golden eagles in the coastal range of California east of San Francisco
- A part of this population may have been affected by a large wind farm development to generate electric power. Some eagles and other birds have been killed by the blades of the wind turbines.
- I was part of a research team asked to assess whether the eagle population is threatened by the wind turbine development. This involved various field studies carried out some years ago.

Golden Eagle Possible Study Designs

* Traditional experiment is not at all feasible due to the scale involved and the fact one is working with a threatened species

* Monitoring of a control population in addition to the impacted population would be the obvious direct observational approach. Unfortunately there is no control population available.

*The research team concluded that use of a population dynamics model plus field sampling of the impacted population is the only viable option.

Golden Eagle Population Model

The female component of the population was divided into the following stages:

1.	Juvenile	0 - 1 year
2.	Subadult and Non-territorial adult	1-4+ years
3.	Territorial adult breeders	4+ years

Golden Eagle Population Model

Survival rates for all stages to be estimated with radio telemetry on radio tagged birds. (FIELD WORK)

Nesting success (recruitment) rates to be estimated from ground searches for nests. (FIELD WORK)

Transition from Subadult or Non Territorial adult to Territorial adult hard to estimate ($1-\alpha$). One would need long term radio-telemetry for this.

Golden Eagle Population Model

Population Parameters

F_T - female fledglings/female

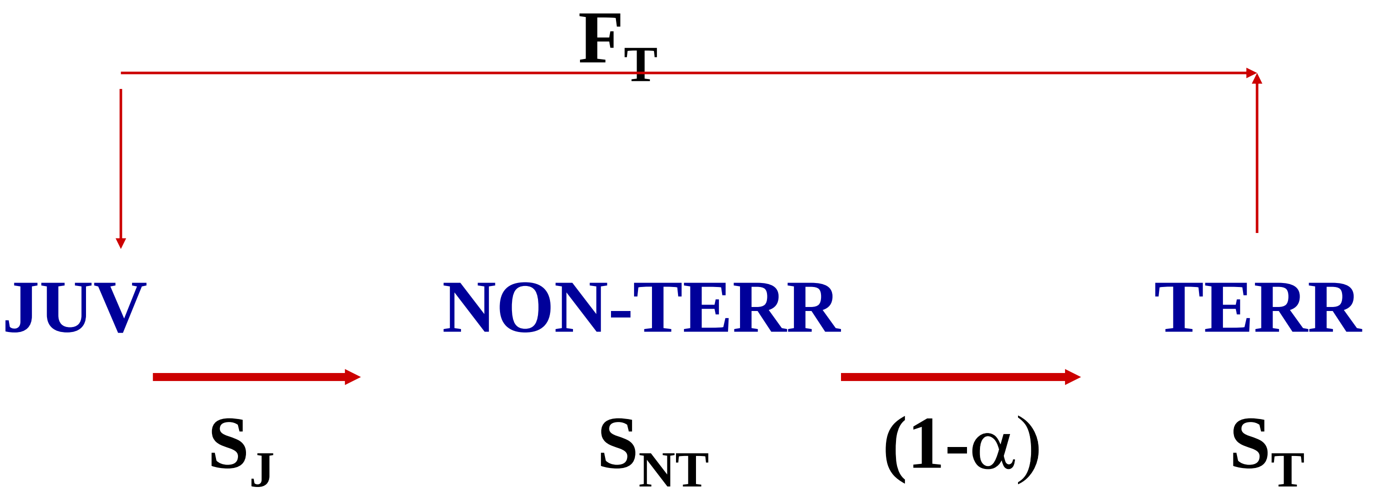
S_J - survival rate of juveniles

S_{NT} - survival rate of non territory holders

S_T – survival rate of territory holders

α – probability of staying a nonterritory holder.

Matrix Model Flowchart for Eagle Example



Matrix Model Structure

Population Projection Equation

$$\underline{n}_{t+1} = \underline{\underline{A}}\,\underline{n}_t$$

$\underline{n}$ is 3x1 vector of popn sizes in each stage at time t or t+1.

$$\underline{\underline{A}} = \begin{bmatrix} 0 & 0 & S_T F_T \\ S_J & S_{NT}\alpha & 0 \\ 0 & S_{NT}(1-\alpha) & S_T \end{bmatrix}$$

Golden Eagle Population Model

Approx Values S_J=0.5, S_{NT}=S_T=0.85, α=0.95, F_T=1. Based on field estimates.

After a variety of runs based on several years of field data the conclusion was the population was approx stable (ie λ ~1.)

The wind farm at least did not appear to be driving λ below 1 but the inference was weak and uncertain.

Golden Eagle Design Strengths

- Practicality

  Short time scale

  Reasonable costs

- Experimental approaches impossible

  No randomization

  No replication

Golden Eagle Design Weaknesses

Results are model dependent and hence depend on the very strong model assumptions being made.

- stable age structure

- survival and recruitment do not vary over time because the time scale of the field studies quite short

- survival and recruitment are estimated without bias from the field sampling studies.

- difficult to get good estimates of $(1-\alpha)$, the probability of becoming a territory holder.

Other Model Based Examples: Influence of Dam Removal on Salmon

Interesting variation on this theme is

Karieva et al. (2000).Recovery and management Options for Spring/ Summer Chinook salmon in the Columbia River Basin. Science 290, 977-979.

This paper looks at the influence of dam removal on the status of salmon populations using a model based approach backed up by an enormous amount of field study of these populations.

They refer to their approach as a “numerical experiment”. Clearly many of these dams are never going to be removed in this system.

Salmon Example:Population Matrix Model Approach

- There are 5 age classes.
- Animals do not live past age 5.
- Table 1 shows structure of the model.
- The key aspects are the equations for downstream survival and movement at age 2 (s_2) and the upstream movement of the spawners (μ)
- Summary on next two slides
- The model is deterministic. That is no year to year variation in the parameters is allowed

Population Parameters (Table 1)

b_3, b_4, b_5 - propensity to breed of 3-5 yr olds

s_x, - survival rate of salmon of age x-1 to x

m_x - number of eggs per female spawner of age x.

(Divided by two to get female eggs)

$s_2 = [zs_z + (1-z)s_d]s_e$

They have to survive going down river either by being transported or surviving the turbines, and through the estuary

μ – survival rate during upstream migration (includes escaping harvest)

$\mu = (1-h_{ms})s_{ms}(1-h_{sb})s_{sb}$

Population Projection Equation (Table 1)

$$\underline{n}_{t+1} = \underline{\underline{A}}\,\underline{n}_t$$

$\underline{n}$ is 5x1 vector of popn sizes in each stage at time t or t + 1.

$$\underline{\underline{A}} = \begin{bmatrix} 0 & 0 & \mu s_1 b_3 m_3 / 2 & \mu s_1 b_4 m_4 / 2 & \mu s_1 b_5 m_5 / 2 \\ s_2 & 0 & 0 & 0 & 0 \\ 0 & s_3 & 0 & 0 & 0 \\ 0 & 0 & (1-b_3) s_4 & 0 & 0 \\ 0 & 0 & 0 & (1-b_4) s_5 & 0 \end{bmatrix}$$

Salmon Example

- "Baseline" Model parameter values are given in Table 2.
- In this case they are a worst case scenario (their term)!
- Note in particular s_d and s_e. Only 20% make it if they go through the turbines. Also the survival in the estuary and entry to the ocean is less than 2%.
- Also note that harvests are low or non existent so not exactly a worst case scenario?
- These result in a population growth rate of $\lambda = 0.760$.

Salmon Example

- They then ask what various management actions will do to the population growth rate?

- How much will the growth rate increase and will that increase be enough to make the population sustainable?

($\lambda = 1$ or more)

- Some of these actions would involve the removal of four dams and some not.

Salmon Example Potential "Management" Actions

- **Eliminate all migration mortality (upstream and down). This would involve dam removal and still would not get the popns to $\lambda=1$. Figure 2.**
- **Three past management options that would not involve dam removal are shown in Figure 4.These did increase popn growth rate but did not get it to $\lambda=1$.**

1. **Harvest Reduction in River**
2. **Engineering Improvements to reduce downstream mortality of juvenile fish**
3. **Transportation of juveniles downstream to avoid dams.**

Salmon Example Potential "Management" Actions

- **Combinations of improved first year survival and early estaurine and ocean survival . This option is the only one that gets λ=1. It is clear that these are the most sensitive parameters but it is not totally clear how to manage the populations to achieve these gains. Dam removal would help but how much?**
- **It seems to me that a Key Point is that they don't want biologists and managers to automatically assume that dam removal would solve the problem for the species.**

Manatee Population Modelling

Runge, Langtimm and Kendall (2004). A stage based model of manatee population growth. Marine Mammal Science 20, 361-385.

Very important threatened marine mammal species in Florida. Survival is impacted by boat strikes.

Some information on popn size from aerial surveys and I have been involved in their design.

I have also been involved in their survival estimation using photo id tag-recapture studies.

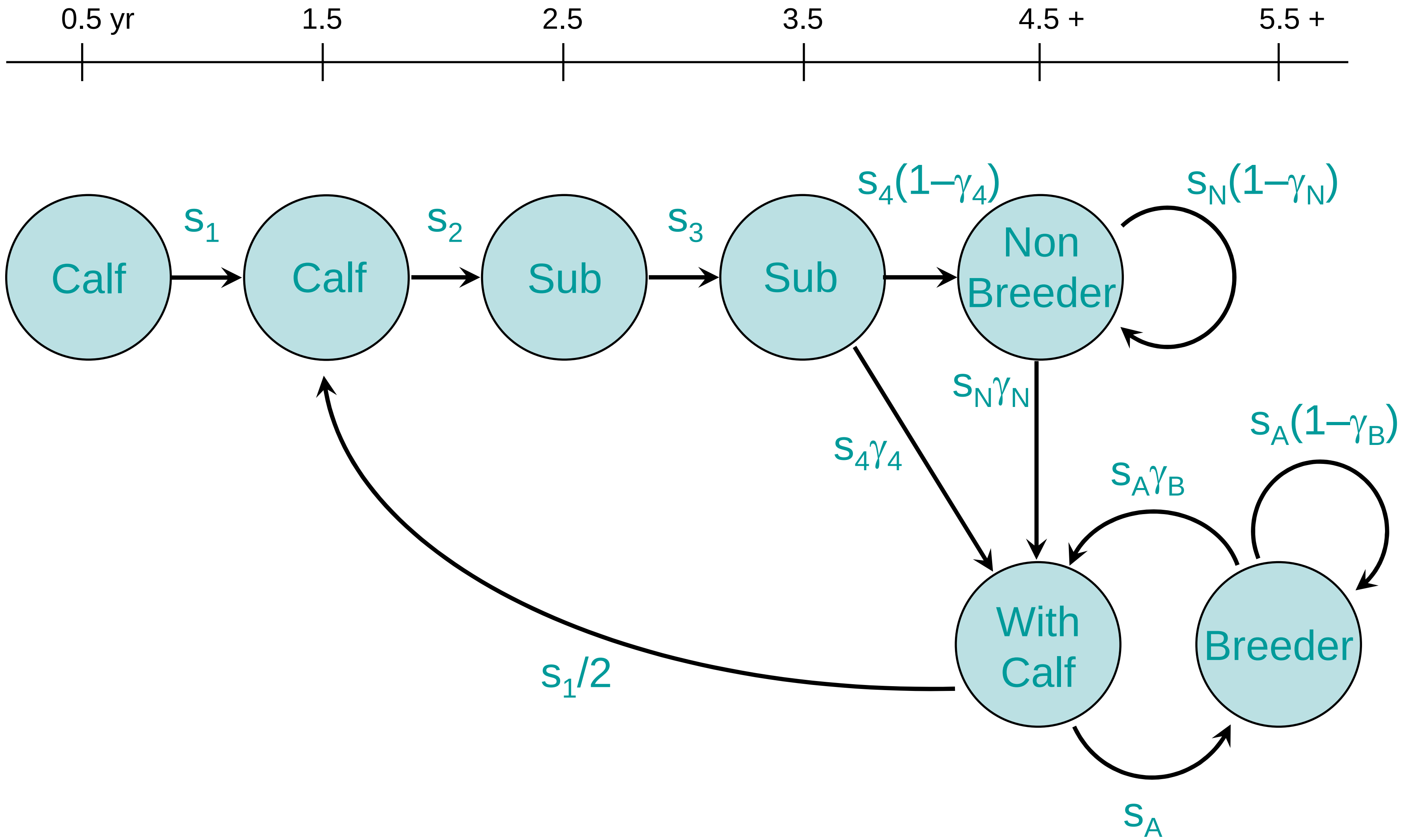
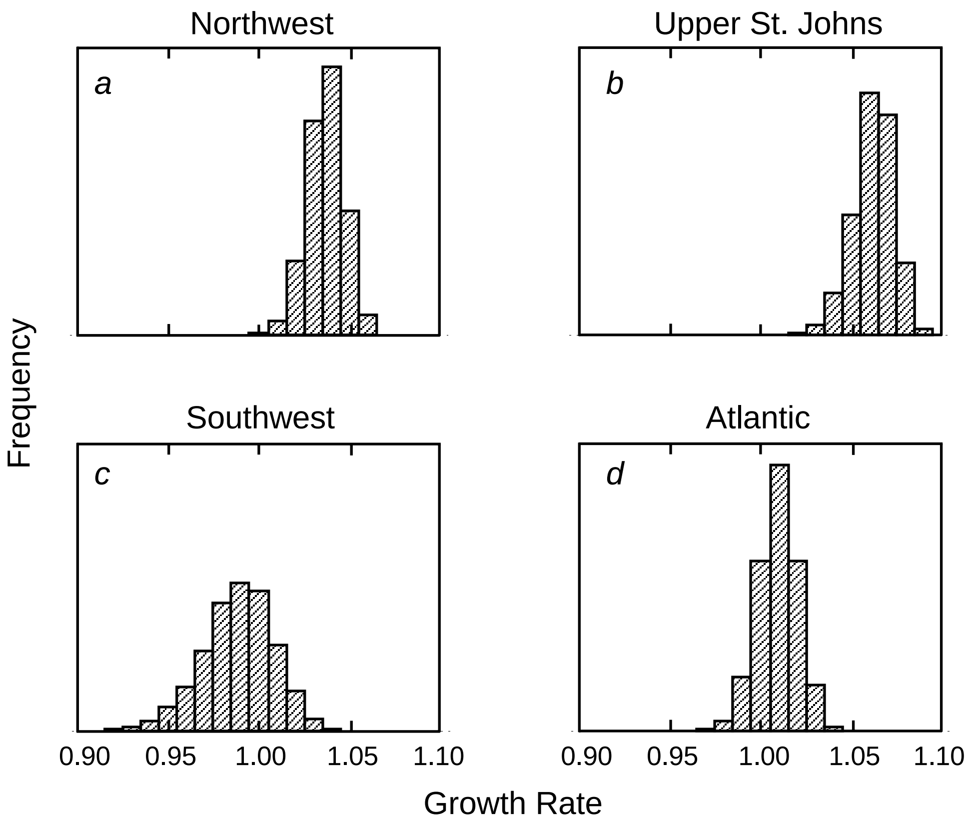

0.5 yr
1.5
2.5
3.5
4.5 +
5.5 +
Calf
Calf
Sub
Sub
Non Breeder
With Calf
Breeder
s_1
s_2
s_3
$s_4(1-\gamma_4)$
$s_N(1-\gamma_N)$
$s_N\gamma_N$
$s_4\gamma_4$
$s_A(1-\gamma_B)$
$s_A\gamma_B$
$s_1/2$
s_A

Table 1. Life-history parameter estimates for Florida manatees in the four regions. Values in **bold** are direct estimates of the appropriate parameter from published studies or recent analyses. Values in roman type are inferred. The "uncertainty" column represents a range of potential values for each parameter; in general, this is the 95% confidence interval for the parameter estimate.

Parameter	Northwest		Upper St. Johns		Southwest		Atlantic [†]	
	Estimate	Uncertainty	Estimate	Uncertainty	Estimate	Uncertainty	Estimate	Uncertainty
s_1	0.81	(0.67, 0.90)	**0.81**	**(0.73, 0.87)**	0.77	(0.62, 0.87)	0.79	(0.65, 0.89)
s_2	0.91	(0.75, 0.97)	**0.92**	**(0.83, 0.96)**	0.86	(0.65, 0.96)	0.89	(0.71, 0.97)
s_3	0.96	(0.94, 0.97)	**0.96**	**(0.92, 0.98)**	0.91	(0.87, 0.94)	0.94	(0.92, 0.95)
s_4	0.96	(0.94, 0.97)	**0.96**	**(0.92, 0.98)**	0.91	(0.87, 0.94)	0.94	(0.92, 0.95)
s_P	**0.96**	**(0.94, 0.97)**	**0.96**	**(0.94, 0.98)**	**0.91**	**(0.87, 0.94)**	**0.94**	**(0.92, 0.95)**
s_A	**0.96**	**(0.94, 0.97)**	**0.96**	**(0.94, 0.98)**	**0.91**	**(0.87, 0.94)**	**0.94**	**(0.92, 0.95)**
γ_4	**0.00**	**(0.00, 0.29)**	**0.21**	**(0.07, 0.42)**	0.0	(0.0, 0.3)	0.0	(0.0, 0.3)
γ_P	**0.38**	**(0.18, 0.62)**	**0.61**	**(0.51, 0.71)**	**0.30**	**(0.13, 0.53)**	0.30	(0.13, 0.53)
γ_B	**0.43**	**(0.22, 0.54)**	**0.61**	**(0.51, 0.71)**	**0.60**	**(0.42, 0.75)**	**0.38**	**(0.29, 0.47)**

[†] The survival rates shown are based on the mean for 1990-1999. The corresponding survival rates for a 5-yr mean (1995-1999) in the Atlantic region are: s_1 = 0.76 (0.61-0.87); s_2 = 0.86 (0.64-0.95); $s_3 = s_4 = s_A = s_P$ = 0.90 (0.87-0.93).



Northwest
Upper St. Johns
Southwest
Atlantic
a
b
c
d
Frequency
0.90
0.95
1.00
1.05
1.10
Growth Rate

Loggerhead Sea Turtle Population Modeling

Crowder, Crouse, Heppell and Martin (1994). Predicting the impact of Turtle excluder devices on loggerhead sea turtle populations. Ecological Applications 4, 437-445.

Another example of a question where no other approach is feasible.

Other Model Based Examples: Hunting Effects

Turkey hunting season example discussed in earlier lecture can be tackled using a modelling approach but is not discussed here.

•Alpizar-Jara, R.., Brooks, E.N., Pollock, K.H., Steffen, D., Pack, J.C., and Norman, G.W. (2001). An eastern wild turkey population dynamics model for the Virginias. *Journal of Wildlife Management* 65, 415-424.

•Brooks, E.N., Alpizar-Jara, R., Pollock, K.H., Steffen, D., Pack, J.C., and Norman, G.W. (2002). An on-line wild turkey population dynamics model. *Wildlife Society Bulletin* 30, 41-45.

Other Model Based Examples: Fisheries Stock Assessments

Fisheries Stock Assessments –Classic examples of use mechanistic models in combination with field work (to estimate input parameters) to assess status of a fishery.

Hilborn and Waters (1992). Quantitative Fisheries Stock Assessment. Chapman and Hall.

Quinn and Deriso (1999). Quantitative Fish Dynamics. Oxford University Press.

Discussed in detail in Joe Hightower's class.

Parameter Estimation from Field Sampling

- Why am I talking about this in a course on field studies?
- Modeling is a sterile line of research unless it is coupled with good estimates from the population under study. This is where the tie to field sampling design and statistics lies!
- Clear therefore that one needs to have good biological, mathematical and statistical knowledge for this type of research approach. Also suggests value of the research team approach.
- The field based sampling parameter estimates are often the weakest link! Despite the best field efforts possible sometimes some of the model parameters will have to be guessed at based on life history characteristics and other biological knowledge. This weakens the inference profoundly.

General Field Sampling Design Issues

- Specific approaches to the field sampling depend on the application.
- Minimise bias and maximise precision of the estimates so that accurate estimates are used in the mathematical models.
- Ideally the sampling should be over multiple years so that stochastic variation in parameters (which is usually important and should be included) can be based on field sampling. This increases the costs!
- Also Does your model need to have spatial structure (i. e. is it a metapopulation system)? If so then one needs special field sampling for all the required parameters. This increases the costs.

Sampling Design Issues: Inclusion of Temporal Variation in Parameters.

- Parameters usually vary from year to year.
- The simplest mathematical models are deterministic and do not allow for this.
- First key point- get estimates based on multiple years of data.
- Second key point-get an estimate of how variable these parameters are based on field sampling? This is not a trivial statistical task!

Sampling Design Issues: Estimation of Temporal Variation in Parameters.

First The Truth

$S_1, S_2, ..., S_k$

k years of field census.

Obtain the variance of these values in the usual way

to get $\tau^2 = \sum_1^k (S_i - \bar{S})^2 / (k-1)$.

This is the true process variation. Of course we never know it!!!

Sampling Design Issues: Estimation of Temporal Variation in Parameters.

The Naïve Approach to Estimation

$\hat{S}_1, \hat{S}_2, \ldots, \hat{S}_k$

k years of field data.

Obtain the variance of these values in the usual way

to get $\hat{\tau}^2 = \dfrac{\sum_{1}^{k} (\hat{S}_i - \bar{S})^2}{(k-1)}$

This is a grossly positively biased estimate of the true process variation. It is very widely used though.

It contains the true process variance plus variance due to estimation.

We need to separate them for a valid estimate.

Sampling Design Issues: Estimation of Temporal Variation in Parameters.

The Valid Approach to Estimation

$\hat{S}_1, \hat{S}_2, \ldots, \hat{S}_k$

Obtain the total variance estimate

$$s^2 = \sum_1^k (\hat{S}_i - \bar{S})^2 / (k-1).$$

If the estimates are independent then

$$\hat{\tau}^2 = \frac{\sum_1^k (\hat{S}_i - \bar{S})^2}{(k-1)} - \frac{\sum_1^k \hat{\text{var}}(\hat{S}_i ! S_i)}{k}.$$

The second term is the estimation component of variance.

Sampling Design Issues: Estimation of Temporal Variation in Parameters.

The Valid Approach to Estimation

If the estimates are not independent then more general

$$\hat{\tau}^2 = \frac{\sum_{1}^{k}(\hat{S}_i - \bar{S})^2}{(k-1)} - \frac{\sum_{1}^{k}\hat{\text{var}}(\hat{S}_i ! S_i)}{k} + \frac{2\sum_{i<j} Cov(\hat{S}_i . \hat{S}_j ! S_i, S_j)}{k(k-1)}$$

The second and third terms have the estimation component of variance.

Sampling Design Issues: Estimation of Temporal Variation in Parameters.

- See Gould and Nichols(1998). Estimation of Temporal Variability of Survival in Animal Populations. Ecology 79, 2531-2538.
- They develop the equations given earlier.
- The equations apply to any parameters-not just survival parameters.
- Examples
  - Roseate Terns-
  - Black Capped Chickadees
  - Mallards

Sampling Design Issues: Estimation of Temporal Variation in Parameters.

- Roseate Terns

$$s^2 = 0.01704$$
$$\hat{\tau}^2 = 0.00530$$
$$\hat{\tau} = 0.0728$$

- Black-capped Chickadees

$$s^2 = 0.01398$$
$$\hat{\tau}^2 = 0.00151$$
$$\hat{\tau} = 0.0389$$

- Mallards

Many Data Sets

$$\hat{\tau}^2 = +,0,-$$

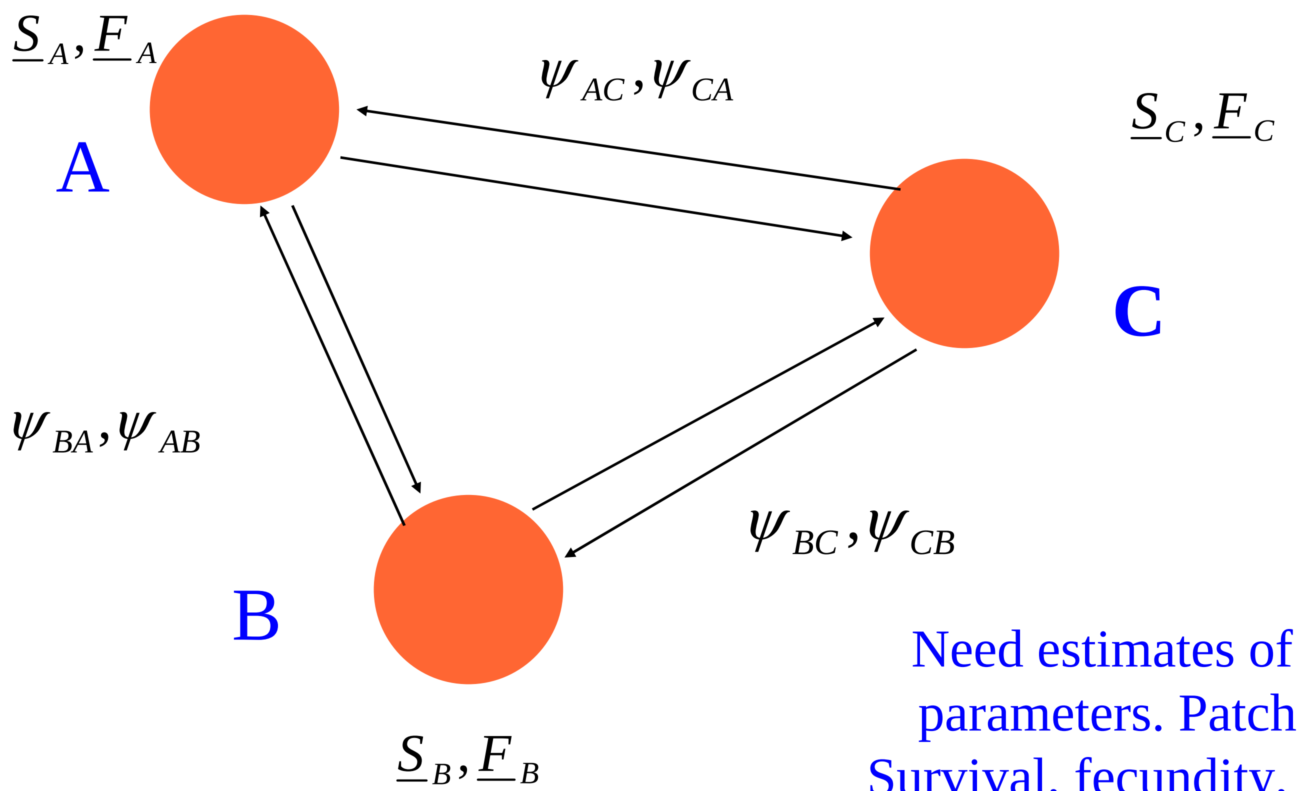
Sometimes negative, See Paper.

τ^2 often very small.

Sampling Design Issues: Metapopulations

- Each patch needs survival and fecundity rates.
- Also need movement rates between the patches.
- See Next Slide for a schematic representation of a very simple metapopulation system

Simple 3 Patch Meta Population System for Illustration



Need estimates of all these parameters. Patch specific Survival, fecundity, movement rates. Preferably with temporal variation.

Sampling Design Issues: Metapopulations

- How to get this information?
- I don’t see any really good way to get the estimates without using tagged animals.
- Larger animals use telemetry or other high tech tags.
- Tag recapture methods use applied tags, natural tags (dna, trace element signatures for fish).
- Given a tag then in principle estimates can be obtained using multi-state capture-recapture models (ST 506). In practice the estimates can be very hard to obtain.