Marine Mammal Capture-Recapture Workshop

May 2009

Kenneth H. Pollock

Professor of Zoology, Biomathematics, and Statistics

231 David Clark Labs

919-515-3514

pollock@unity.ncsu.edu

COURSE OUTLINE

Introduction

- **-Estimation of Animal Abundance**
- **-Statistical Inference and Sampling Models**
- **-Estimators and Their Properties**

Closed Models

- **- Estimating Abundance using Lincoln-Petersen Model**
- **- Extensions with focus on unequal catchability of animals**
- **- Special issues with Natural Tags**

Open Models

- **-Estimating Apparent Survival Rates**
- **-Estimating Movement, and Other Transitions in Multi-State Models**
- **-Estimating Abundance and Recruitment**

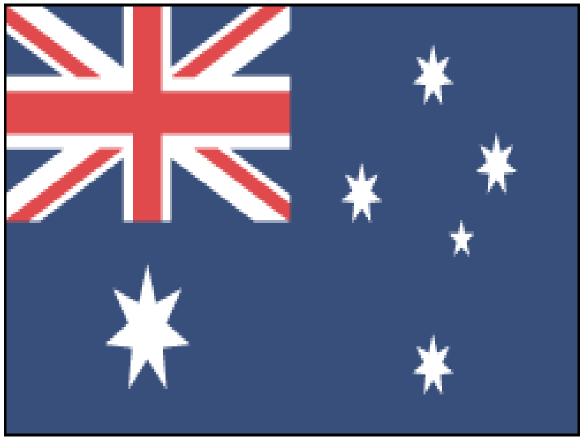
The Robust Design

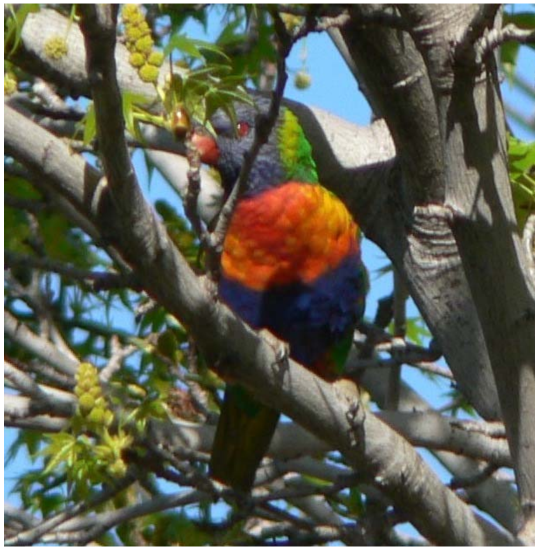
- **-Combining Closed & Open Mark-Recapture Models.**

Use of Natural Tags in Capture-Recapture Models

- **-Unmarkable Animals, Misidentification Effects on Estimation.**

My Introduction: Australian





Rural New South Wales

Sydney University: B Sc.

Cornell University, Ithaca NY: MS & Ph D.

MY SCIENCE PHILOSOPHY

- Develop better sampling methods and statistical models so that ecologists can be more effective in doing good science. This can aid natural resource managers in making better decisions.
- Statisticians need to be well trained in mathematical statistics.
- Statistics can be viewed as a servant of the sciences
- Applied statisticians need to understand the discipline they are collaborating with in enough depth so that true communication and hence collaboration can occur.
- In my personal case this means being knowledgeable about ecology and applied ecology (fisheries and wildlife conservation biology).

RESEARCH DIRECTIONS

Sampling Animal Populations

Capture-Recapture and Tag-Return Models

Better robust models for estimation of demographic parameters such as population size, survival rates, birth rates etc.

Recently focus on natural tags which include genetic (dna) and natural marks. How to allow for misidentification errors in capture-recapture models. How these models apply to marine mammal populations.

RESEARCH DIRECTIONS

Sampling Animal Populations

Radio-Telemetry Survival Models

Better models to estimate survival and components of mortality with special tag radio & sonic tags.

Line and Strip Transect Surveys (Aerial Surveys)

Improved aerial survey methods for counting marine mammals to estimate population size.

Point Count Surveys (Birds)

Improved methods of counting forest birds to estimate population density.

RESEARCH DIRECTIONS

RECREATIONAL FISHING SURVEYS

•Many marine fisheries are over exploited and many have a recreational component. I have worked on developing better methods of sampling the recreational fishing sector using surveys and have written a book on the topic.

•I was asked to be on a National Academy of Science Panel on this topic. The US government is very concerned at the state of our marine fisheries and the poor data available for their assessment.

INTRODUCTIONS

Your name

Your university education and background

Your research interests in marine mammals

Why are you at the workshop?

Do you enjoy statistics/mathematics?

SOFTWARE

MARK-We will spend a lot of time showing you many features of this amazing software

CAPTURE FROM MARK-still useful although old software.

POPAN FROM MARK-extremely important for modelling open populations.

RMARK-briefly at the end

MARK

- User friendly windows based program for capture-recapture,telemetry and band return models
- Many options and can run CAPTURE and POPAN from MARK
- Uses AIC for model selection and Allows multiple groups, age classes, multi-state extension, covariates
- Can download from their web site.Can also download an online book and other resources.

http://welcome.warnercnr.colostate.edu/~gwhite/mark/mark.htm
http://www.phidot.org/software/mark/docs/book/

Key References

Williams et al. (2002). Analysis and Management of Vertebrate Populations. Academic Press.

Amstrup et al. (2005). Handbook of Capture-Recapture Methods. Princeton University Press.

Pollock et al. (1990). Statistical Inference for Capture-Recapture Models. Wildlife Society Monograph. (pdf available). Old but still useful.

Mark Online Book. Evan Cooch and Gary White.

COURSE OUTLINE

Introduction*

-Estimation of Animal Abundance

-Statistical Inference and Sampling Models

-Estimators and Their Properties

Closed Models

- Estimating Abundance using Lincoln-Petersen Model

- Extensions with focus on unequal catchability of animals

- Special issues with Natural Tags

Open Models

-Estimating Apparent Survival Rates

-Estimating Movement, and Other Transitions in Multi-State Models

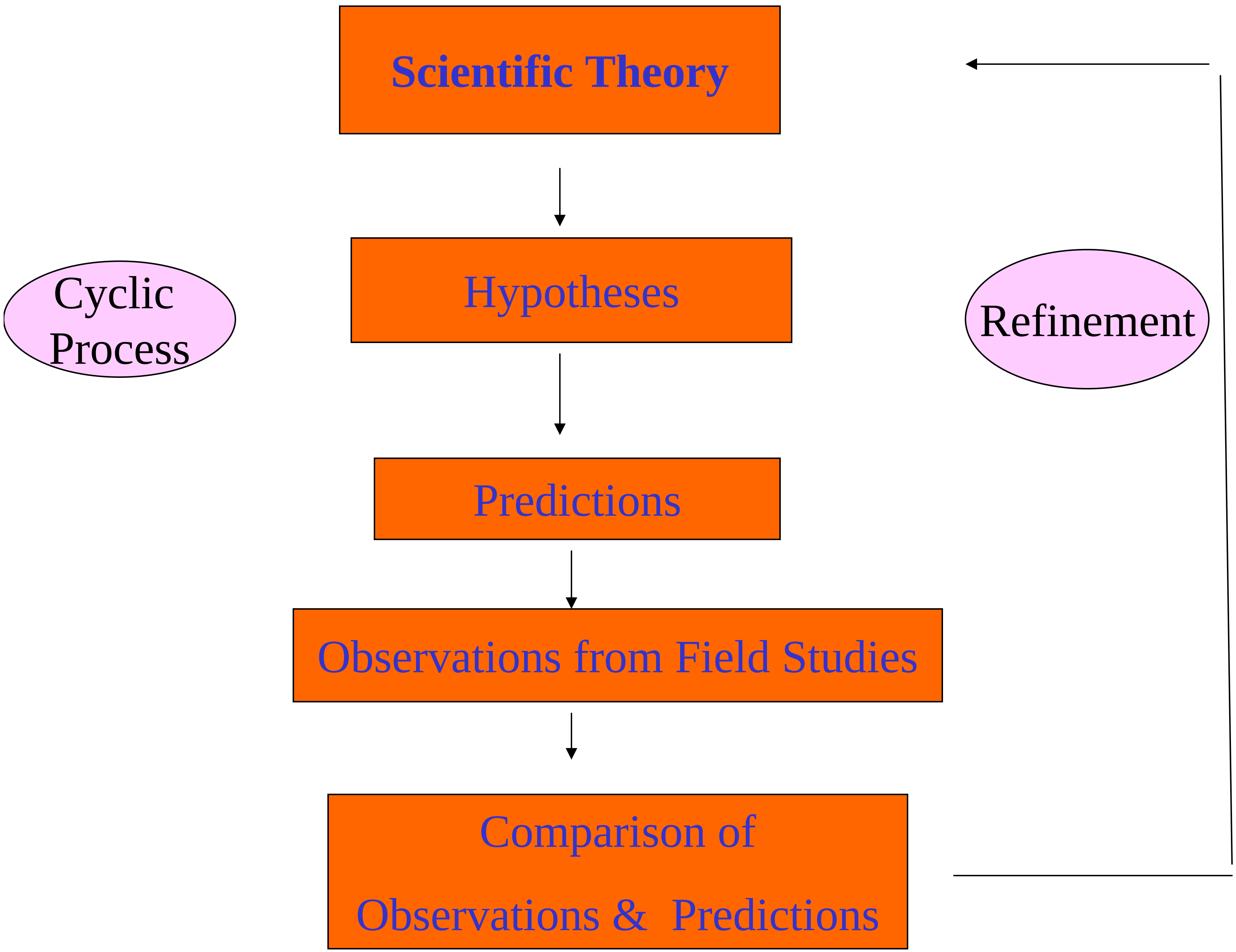
-Estimating Abundance and Recruitment

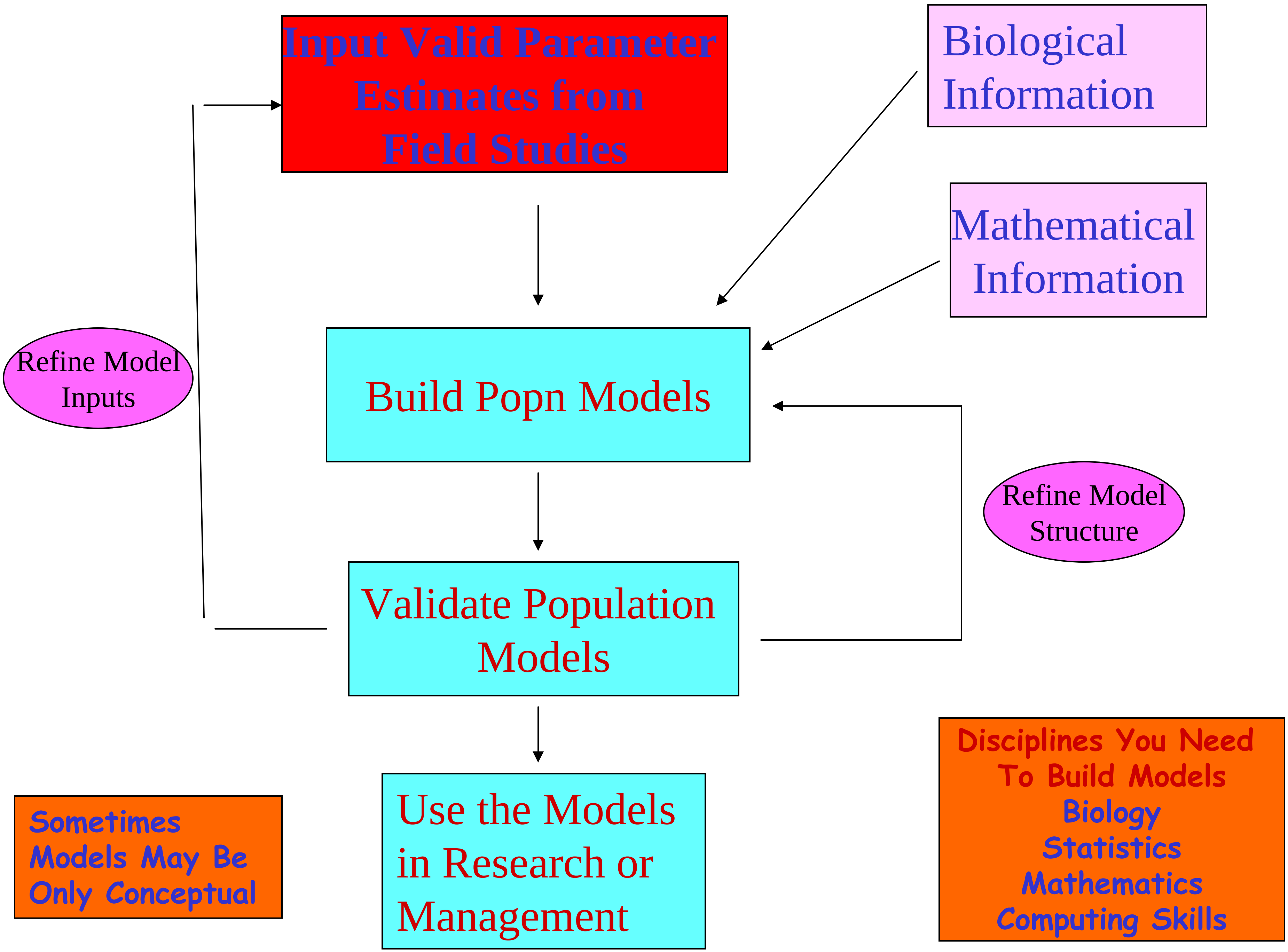
The Robust Design

-Combining Closed & Open Mark-Recapture Models.

Use of Natural Tags in Capture-Recapture Models

-Unmarkable Animals, Misidentification Effects on Estimation.


Scientific Theory
Hypotheses
Predictions
Observations from Field Studies
Comparison of
Observations & Predictions
Cyclic
Process
Refinement


Input Valid Parameter Estimates from Field Studies
Biological Information
Mathematical Information
Refine Model Inputs
Build Popn Models
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

WHY ASSESS POPULATIONS?

- Animal populations are under threat from exploding human populations, development, and pollution.

  Some populations may also be subject to excessive fishing (tuna) or hunting (elephants).

- Need information to form basis of sound objective natural resource management based on scientific methods (often little science, politics, and emotion dominate.

OVERVIEW OF METHODS OF ASSESSING POPULATIONS

Direct methods of monitoring

Census Method

Count all animals in the population
(in usually unrealistic practice)

Sampling Methods

Count animals in sampling units (or areas)

Absolute Abundance

Estimate popn size by adjusting for ‘unseen’ animals and only part of area being sampled

Relative Abundance

Use incomplete count as an ‘index’ of popn size

CENSUS

Usually it is impossible to count all the members of a wildlife population for practical reasons.

- Exceptions are small, localized populations of highly visible and valuable endangered species.

- Examples are the California Condor (now almost extinct* in the wild) and the Puerto Rican Parrot (popn size in wild is only around 35 birds)

*recent releases

ABSOLUTE ABUNDANCE ESTIMATION

Not all area sampled and not all animals ‘seen’

$$\hat{N} = C / \alpha\hat{\beta}$$

C = count of animals seen

α = fraction of area sampled

$\hat{\beta}$ = estimate of the fraction of animals seen or caught

Note: there are many ways to estimate β . For example, capture-recapture, line transects etc.

ABSOLUTE ABUNDANCE ESTIMATION

Example: Aerial survey of caribou in Alaska.

C = count of caribou seen = 551

α = fraction of area sampled= 0.1

$\hat{\beta}$ = estimate of the fraction of animals seen or caught=0.5

Note: there are many ways to estimate β. For example, two independent observers in the plane.

$$\hat{N} = C/\alpha\hat{\beta}$$

$$= 551/(0.1 \text{ x } 0.5)$$

$$= 551 x 10 x 2$$

$$= 11{,}020$$

ABSOLUTE ABUNDANCE ESTIMATION

CAPTURE METHODS

- Capture-Recapture
- Removal and Catch-Effort
- Change-in-Ratio or Selective Removal

COUNT METHODS

- Line Transects
- Variable Circular Plots
- Double Sampling (e.g., ground, aerial)
- Counts from multiple observers with mapping

All can be viewed as methods to estimate β in

$$\hat{N} = C/\alpha\hat{\beta}$$

The Removal Model

We will use this very very simple model to illustrate many properties of estimators that we need to introduce..I deliberately do not use the Lincoln-Petersen model until later!!

REMOVAL MODELS (TWO SAMPLE)

Fish in a pond

n_1 animals captured and removed in sample 1
n_2 animals captured and removed in sample 2

n_1/N fraction removed in the first sample.
$n_2/(N-n_1)$ fraction removed in the second sample.

$$n_1/N = n_2/(N-n_1)$$

REMOVAL MODELS
(TWO SAMPLE)

Fish in a pond

n_1 animals captured and removed in sample 1
n_2 animals captured and removed in sample 2

$$\hat{N} = \mathbf{n_1^2 / (n_1 - n_2)}$$

$\hat{p} = \hat{\beta}$ **= $(n_1 - n_2) / n_1$** estimate of detectability

$$\hat{N} = \mathbf{n_1} / \hat{p}$$

Note: Generalizes to other more general removal and catch effort models.

REMOVAL MODELS (TWO SAMPLE)

Example of Model Based Sampling

Model Assumptions (Validity of Estimator, Bias)

1. Closed Population
2. Equal capture probs for all animals
3. Equal capture probs at time 1 and time 2.

Sample Sizes (Precision of Estimator, Standard error)

Larger sample sizes will give better precision
(i.e. a smaller Standard Error)

Note: Bias and Precision discussed next

SAMPLING ANIMAL POPULATIONS

Statistical Concepts

Population	Sample
	n_1, n_2 data
N-parameter	$\hat{N} = n_1^2 / (n_1 - n_2)$
	Estimator

Statistical inference is to estimate population parameters from the sample data

Precision, Bias and Accuracy

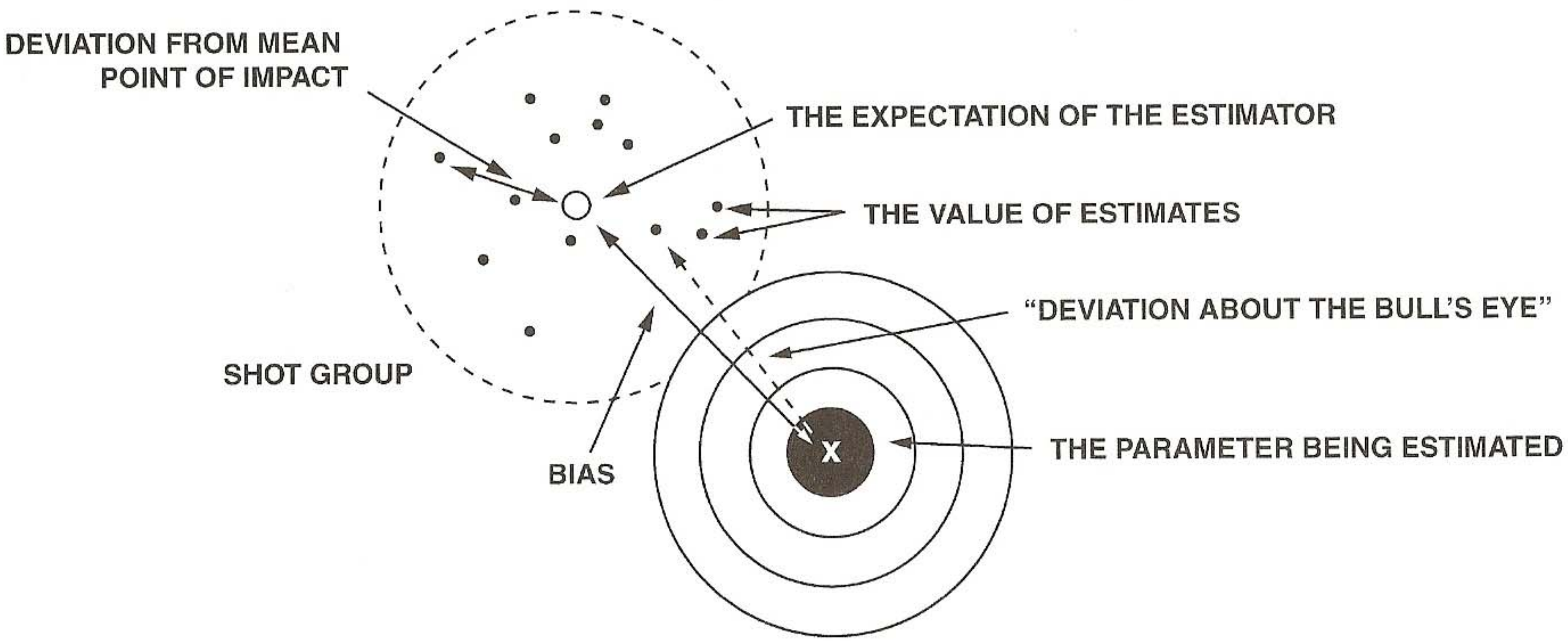


Fig. 1. The analogy of precision, bias, and accuracy in estimation and firing a rifle (from Overton 1969:405).

SAMPLING ANIMAL POPULATIONS

Statistical Concepts

Properties of Estimators

Bias

Difference between mean estimator and true value of parameter

$$Bias(\hat{\theta}) = E(\hat{\theta}) - \theta$$

Note: The expected value is the average over a large number of hypothetical repetitions of the study

SAMPLING ANIMAL POPULATIONS

Precision

Variance-is the average squared deviation of an estimate from its expected value.

$$Var(\hat{\theta}) = E[\hat{\theta} - E(\hat{\theta})]^2$$

Standard Error (SE)-Square Root of the variance.

$$SE(\hat{\theta}) = \sqrt{Var(\hat{\theta})} = \sqrt{E[\hat{\theta} - E(\hat{\theta})]^2}$$

Interpretation: Small variance or Standard Error means good precision on the estimate. (tight shot group but not necessarily centered on bulls eye)

SAMPLING ANIMAL POPULATIONS

Mean Squared Error (MSE)-Accuracy

The MSE-is the average squared deviation of an estimate from its parameter.

$$MSE(\hat{\theta}) = E[\hat{\theta} - \theta)]^2$$

$$MSE(\hat{\theta}) = Var(\hat{\theta}) + [Bias(\hat{\theta})]^2$$

Small MSE means good accuracy (close to bulls eye, low bias and small variance).

SAMPLING ANIMAL POPULATIONS

Statistical Concepts

Methods of Estimation

Method of Moments

Method of Least Squares

Method of Maximum Likelihood

SAMPLING ANIMAL POPULATIONS

Statistical Concepts

Methods of Estimation

Method of Moments

- Simplest method and quite intuitive often.
- It involves equating sample moments to population moments.
- For biology students this will become clearer when I illustrate for the removal model.

Statistical Concepts

Methods of Estimation

Method of Moments

$E(n_1)=Np$

$E(n_2 \text{ given } n_1)=(N-n_1)p$

$$n_1 = \hat{N}\hat{p}$$

$$n_2 = (\hat{N} - n_1)\hat{p}$$

$$\hat{p} = \frac{n_1}{\hat{N}} = \frac{n_2}{\hat{N} - n_1}$$

Solve

$$\hat{N} = n_1^2/(n_1 - n_2)$$

$$\hat{p} = (n_1 - n_2)/n_1$$

SAMPLING ANIMAL POPULATIONS

Statistical Concepts

Methods of Estimation

Method of Least Squares

Used in regression problems in a basic methods course. Will not discuss further here.

SAMPLING ANIMAL POPULATIONS

Statistical Concepts

Methods of Estimation

Method of Maximum Likelihood

- Derive the probability distribution of the observed data as a function of the parameters $p(x;\theta)$

- View this as a function of the parameters, this is the likelihood function

$$L(\theta)$$

- Find the values of the parameters which maximise this function. These are the maximum likelihood estimators (MLEs) $\hat{\theta}$

Method of Maximum Likelihood

Tag Retention Example

R Retained tag L Lost tag

p - prob tag retained, (1 - p) - prob tag lost

$$P(RRLRLRRRRL) = p^7 (1-p)^3$$

$$L(p) = p^7 (1-p)^3$$

The likelihood is maximised at

$$\hat{p} = x/n = 7/10 = 0.7$$

I will plot this out on the whiteboard.

Method of Maximum Likelihood

Methods of Maximising a function

•Set partial derivatives equal to 0. Solve the resulting equations.

•Use a computer package which may use a variety of algorithmns. Often necessary as the likelihoods are so complex with many parameters

SAMPLING ANIMAL POPULATIONS

Method of Maximum Likelihood

Removal Model

Note that the method of moment estimators are also MLEs

$$\hat{N} = n_1^2 / (n_1 - n_2)$$

$$\hat{p} = (n_1 - n_2) / n_1$$

Method of Maximum Likelihood

Removal Model

It is possible to find MLEs mathematically.

$$L(N,p;n_1,n_2)$$

$$= C_{n_1}^{N} p^{n_1}(1-p)^{(N-n_1)}.$$

$$C_{n_2}^{(N-n_1)} p^{n_2}(1-p)^{(N-n_1-n_2)}$$

Use

$$L(N,p)/L(N-1,p)=1$$

and

$$dLogL(N,p)/dp=0$$

SAMPLING ANIMAL POPULATIONS

Maximum Likelihood Estimators Properties

Possible to derive expressions for the large sample variances and SEs of the MLEs

Removal Model

$$\hat{SE}(\hat{N}) = n_1 n_2 (n_1 + n_2)^{1/2} / (n_1 - n_2)^2$$

SAMPLING ANIMAL POPULATIONS

Maximum Likelihood Estimators Properties

For “large samples” (asymptotics) approximatey:

• Unbiased

•Normally distributed

•No other estimator has smaller variance. So “best” in

terms of precision (efficiency).

• Possible to derive expressions for the large sample variances and SEs of the MLEs

SAMPLING ANIMAL POPULATIONS

Confidence Intervals(4.2.3)

Using Asymptotic Normality-for example 95% CI is

$$\hat{N} \pm 1.96\, SE(\hat{N})$$

Using Profile Likelihood Approach

Will not discuss but will be computed in some packages

REMOVAL MODELS (TWO SAMPLE)

Example-Seber (1982) P324.

n_1=49
n_2=26

$\hat{N}$ = $n_1^2 / (n_1 - n_2) = 49^2 / 23 = 104$ (SE=20)

$\hat{p} = \hat{\beta}$ = $(n_1 - n_2) / n_1 = 23/49 = 0.47$

Note- 47% of the animals removed each time.

Approx 95%CI is (104-1.96x20, 104+1.96x20)
or (popn size between 65 and 143 animals)

REMOVAL MODELS
(TWO SAMPLE)

Example-Seber (1982) P324.

Wide Confidence interval even though p large here.With small populations you need a very large removal probability for this method to work well.

Note if p is small the estimate may “fail”! Why? Discuss by referring back to the structure of the equation.

The removal model is very simple but does not work all that well. Methods based on mark and recapture are generally way better!!

SUMMARY

We are using estimation and often find maximum likelihood estimation is the best.

Estimator Properties- Bias and Precision are both important! MSE combines both into an overall measure of accuracy

Summary: Precision, Bias and Accuracy

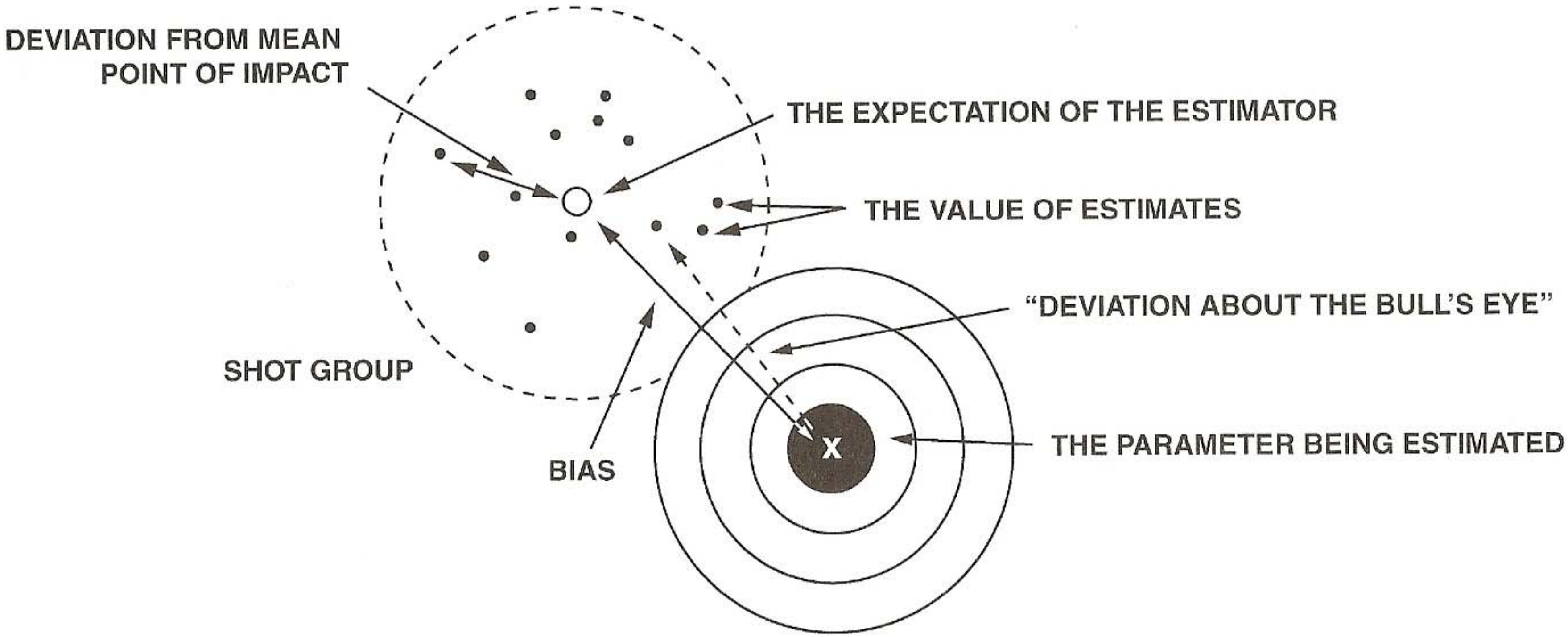


Fig. 1. The analogy of precision, bias, and accuracy in estimation and firing a rifle (from Overton 1969:405).

SUMMARY

We are using model based sampling so assumptions are very important so that we can minimise bias as much as possible

Sample sizes are also important because we want to have estimates with good precision-ie small SE and therefore narrow confidence intervals.

We will return to these two themes repeatedly through the workshop.