Statistical Sampling for the Estimation of River Herring Run Size Using Visual Counts

Ultimate Goal

- How many river herring are migrating into a watershed?
  - Trends in abundance over time tell us about status of the run (i.e., declining?)
  - Knowing abundance allows us to set regulations to ensure continued survival (i.e., fixed escapement)

Two Methods to Measure Abundance

- <u>Census</u>
  - Count every individual
  - Can be extremely time consuming, labor intensive and high cost (e.g., US census)
  - For herring can use:
    - Electronic counter (check and calibrate)
    - Video (have to watch every second of images)

Two Methods to Measure Abundance (cont)

- <u>Statistical Survey Sampling</u>
  - Allows estimation of daily run size based on counts of fish from a small number of short time observations (e.g., 10-min counts)

Typically, statistical techniques are used when visual counting is the primary observation method (can use with other methods too).

Presentation Goals

- Discuss statistical survey methodology
  - Basic Procedures
  - Producing reliable estimates
  - Review of the recommended sampling design
  - Power
  - What if sampling procedures aren’t followed

Basic Statistical Procedure

- Need a “population” from which to take a sample of members
- For us, the “population” will be defined as the total number of time units (e.g., 10-minute intervals) over which herring could be counted

12 hours, 30 minute intervals = 24 intervals; **total fish = 154**

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
0	0	0	3	4	20	22	13	12	9	5	2	0	0	0	2	7	12	16	18	4	3	2	0

- Select randomly a subset (sample) of units, then make counts

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
0	0	0	3	4	20	22	13	12	9	5	2	0	0	0	2	7	12	16	18	4	3	2	0

Basic Statistical Procedure (cont.)

To get daily run size, we first need to estimate:

Mean number of fish per time unit ($\bar{y}$)

12 hours, 30 minute intervals = 24 intervals; true mean = 6.41 fish

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
0	0	0	3	4	20	22	13	12	9	5	2	0	0	0	2	7	12	16	18	4	3	2	0

Sample: $$\bar{y} = \frac{0+0+9+0+18\ fish}{5} = \frac{5.4\ fish}{interval}$$

Basic Statistical Procedure (cont.)

The total number of time units (N) is multiplied by mean ($\bar{y}$) to extrapolate to the total number of fish (Y):

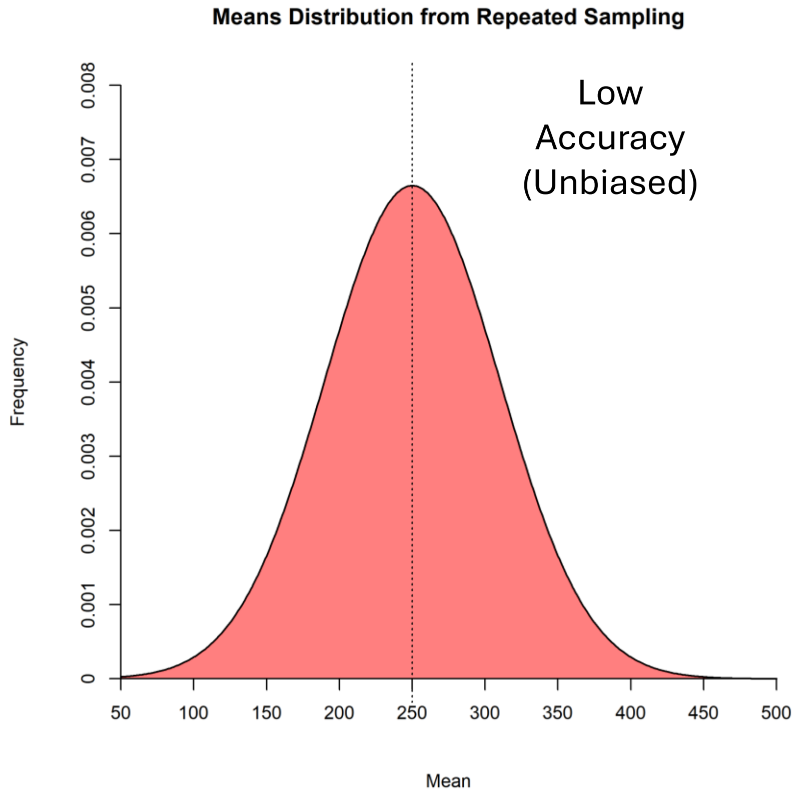
$$Y = \bar{y} \cdot N$$

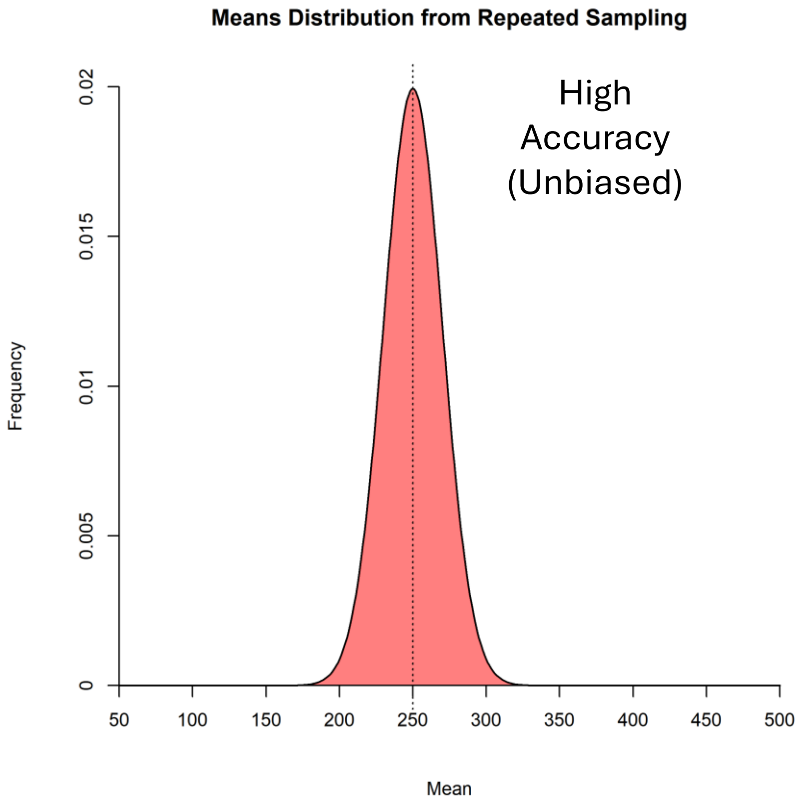
Example: $Y = \frac{5.4\ fish}{interval} \cdot 24\ intervals = 129.6\ fish$

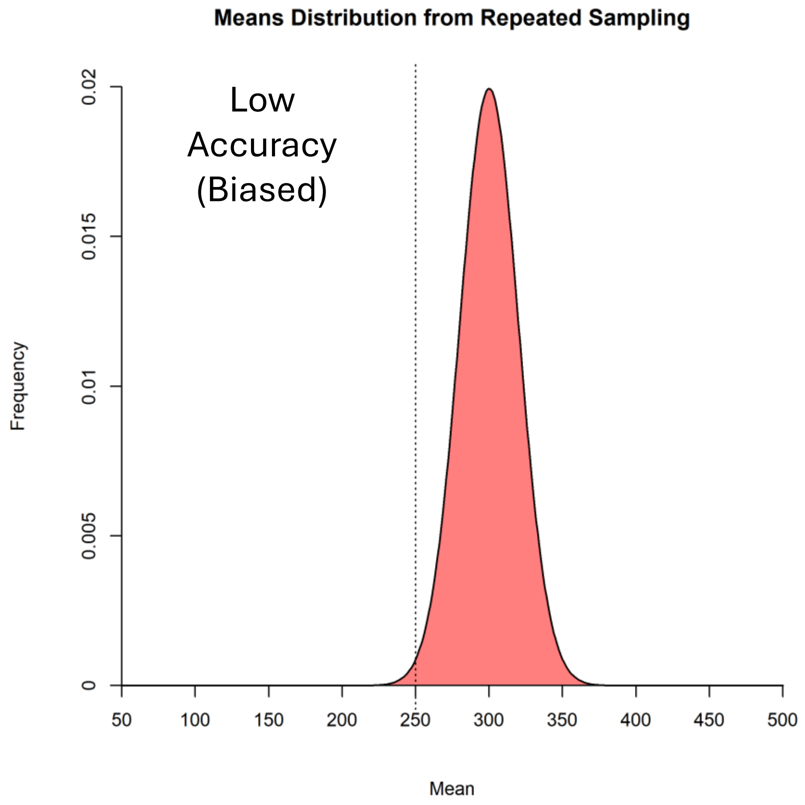
- The mean is the critical statistic (!!!!) and must be estimated accurately and precisely to get a reliable estimate of total number of fish passing

What makes a reliable estimate?

- Accuracy – How close repeated estimates are to the true value







Random selection ensures estimates are unbiased

How to produce unbiased estimates

- Use an estimator (e.g., mean formula) that is known to produce unbiased estimate
- Follow recommended statistical procedures for selecting units!
- Random Selection of Units (without replacement)
- Estimation of statistics is probability-based
  - Each unit has same probability of being selected
  - Selection of one unit has no influence on the selection of another unit
    (Can’t sample contiguous units because of convenience)

How to take a random sample

- Number time units from 1 to total (e.g., 24 thirty-minute intervals in 12 hours)

12 hours, 30 minute intervals = 24 intervals; **total fish = 154**

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
0	0	0	3	4	20	22	13	12	9	5	2	0	0	0	2	7	12	16	18	4	3	2	0

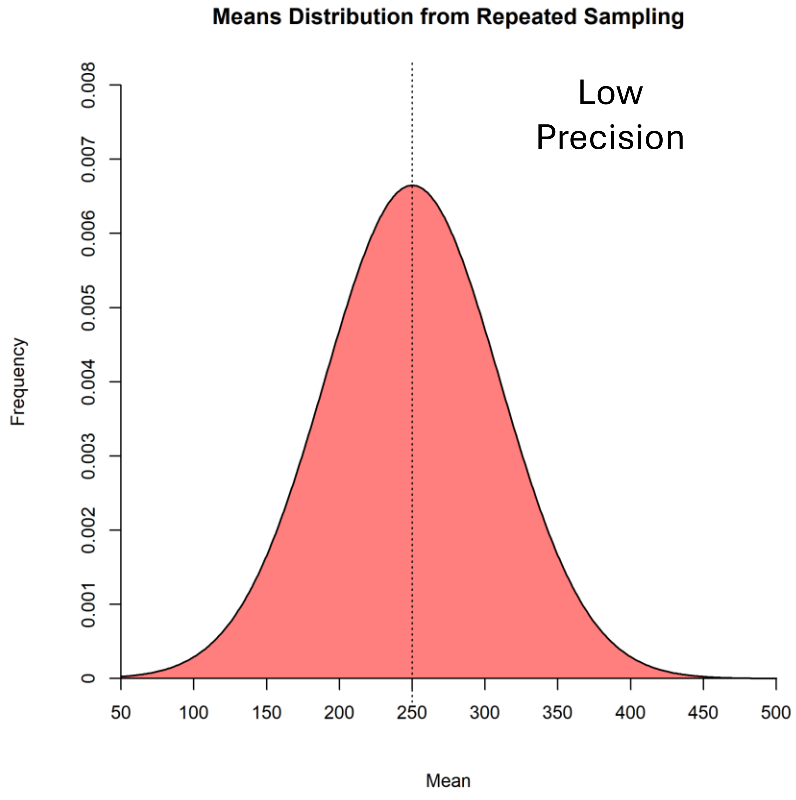
- Use random-number generator to pick subsample of size *n* <u>without</u> replacement (e.g., pick 5 units out of 24)

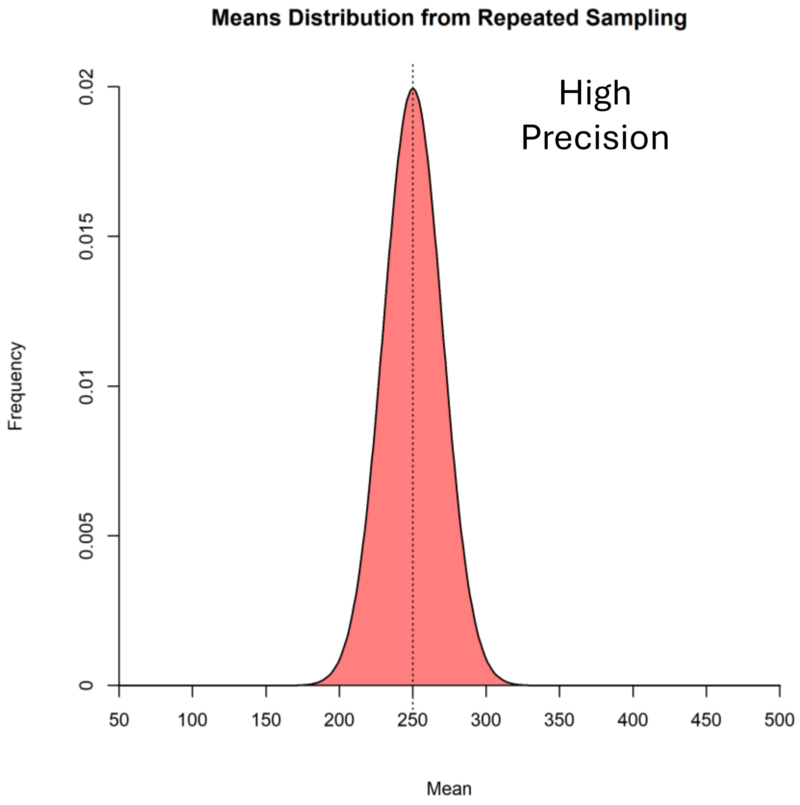
<u>On-line</u>

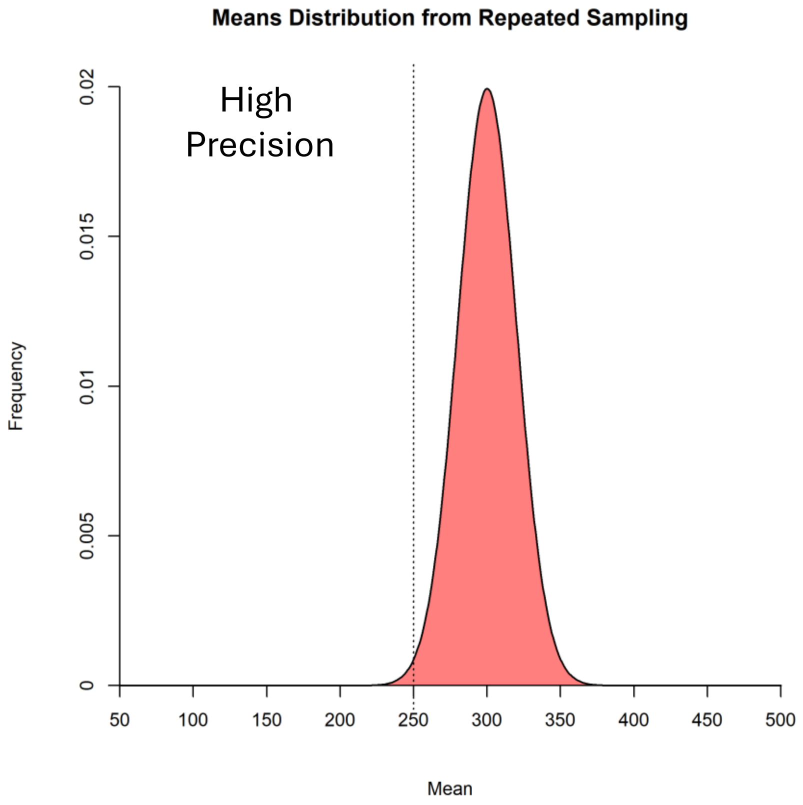
https://www.calculatorsoup.com/calculators/statistics/random-number-generator.php

What makes a reliable estimate?

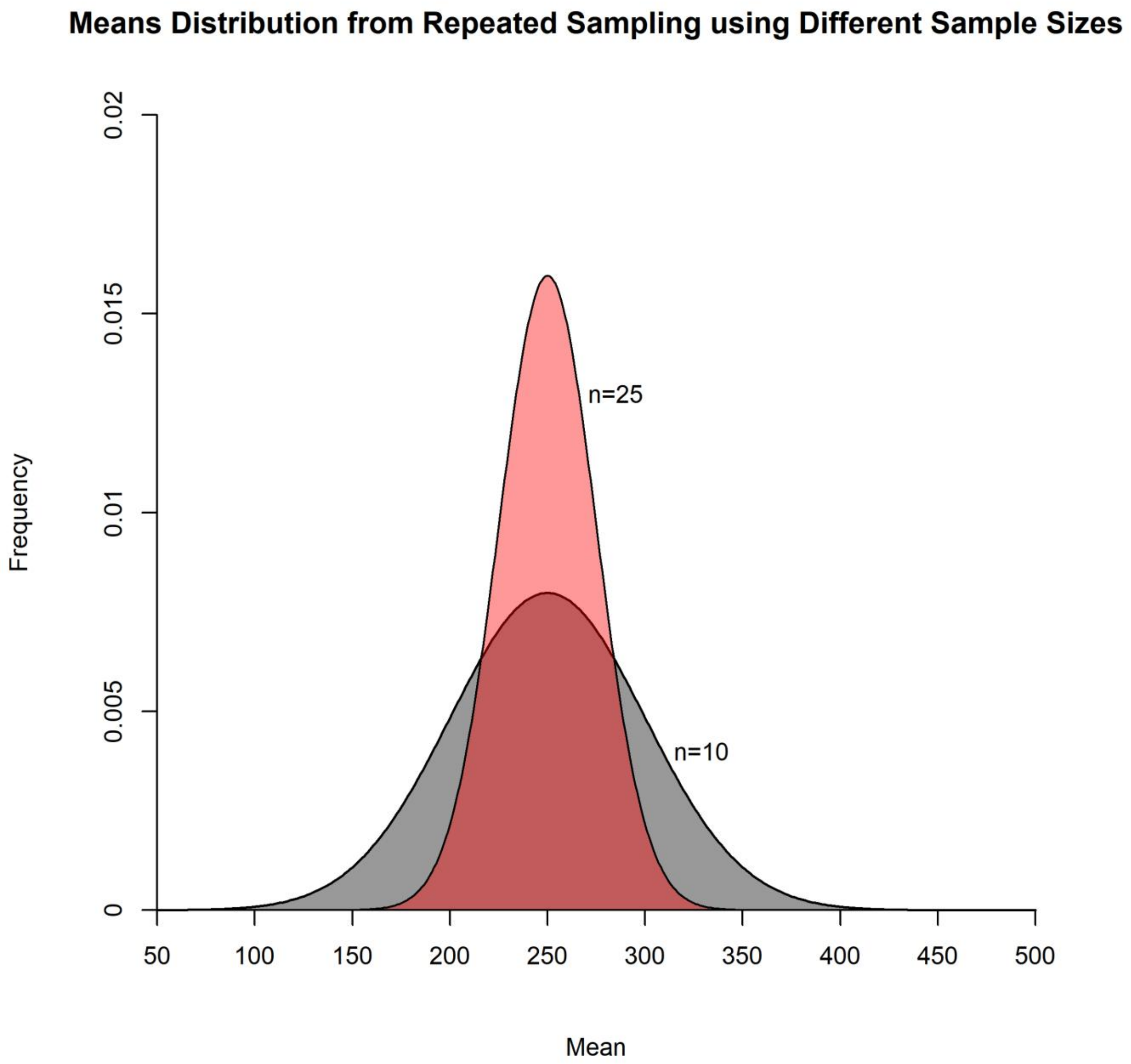
- Precision – How close repeated estimates are to each other







What Ensures Accuracy and Precision?



Sample Size
Controls A/P!

Estimation

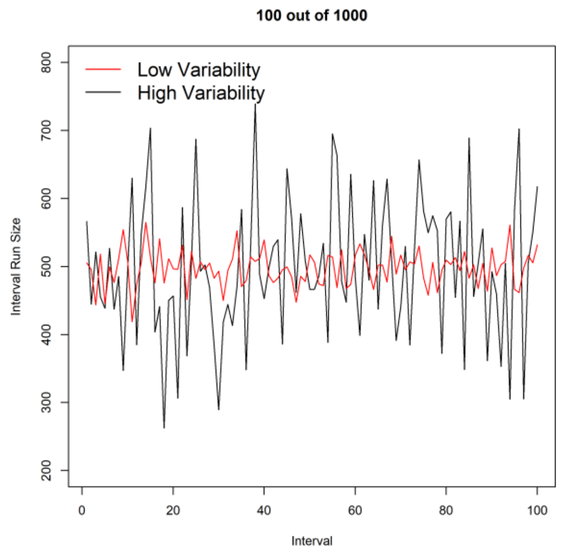
- In reality, we only estimate quantity once

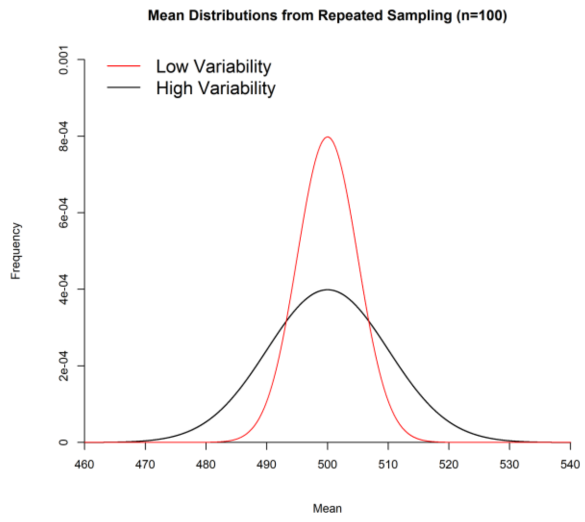
- Need to choose units randomly (ensure unbiased) and select appropriate sample size that will ensure our estimate will lie close to true value

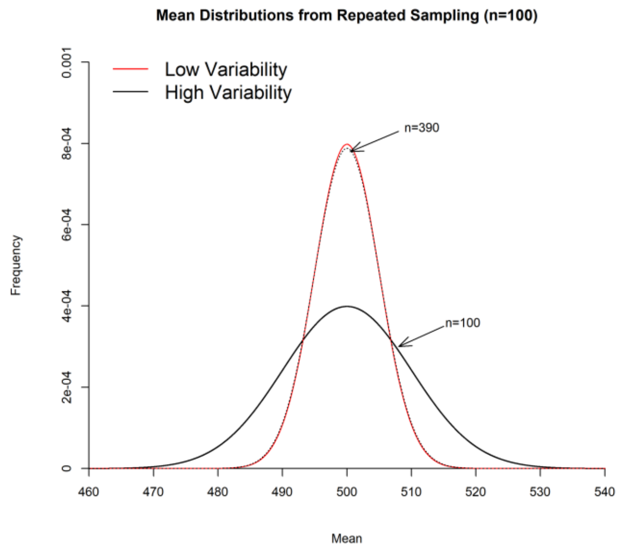
- Sample size determination is a big part of sampling and should be considered <u>before</u> study proceeds from a pilot study usually

Sample Size Determination
(How many intervals should be sampled)

- SSD big part of estimation (Nelson, 2006)
- Desired Level of Precision (could be restricted due to effort limitation)
- Natural Variability of Counts







- Number of Total Intervals (Population)
- If interested in determining significant changes of counts over time - power

Assessing Reliability of Single Estimate

- How can we assess the reliability of an estimate without knowing the true value?
- Confidence intervals!
- CIs are the lower and upper boundaries that theoretically would include the true mean X% of the time if sampling was repeated
- Width gives an indication of reliability/certainty

95% Confidence Limits

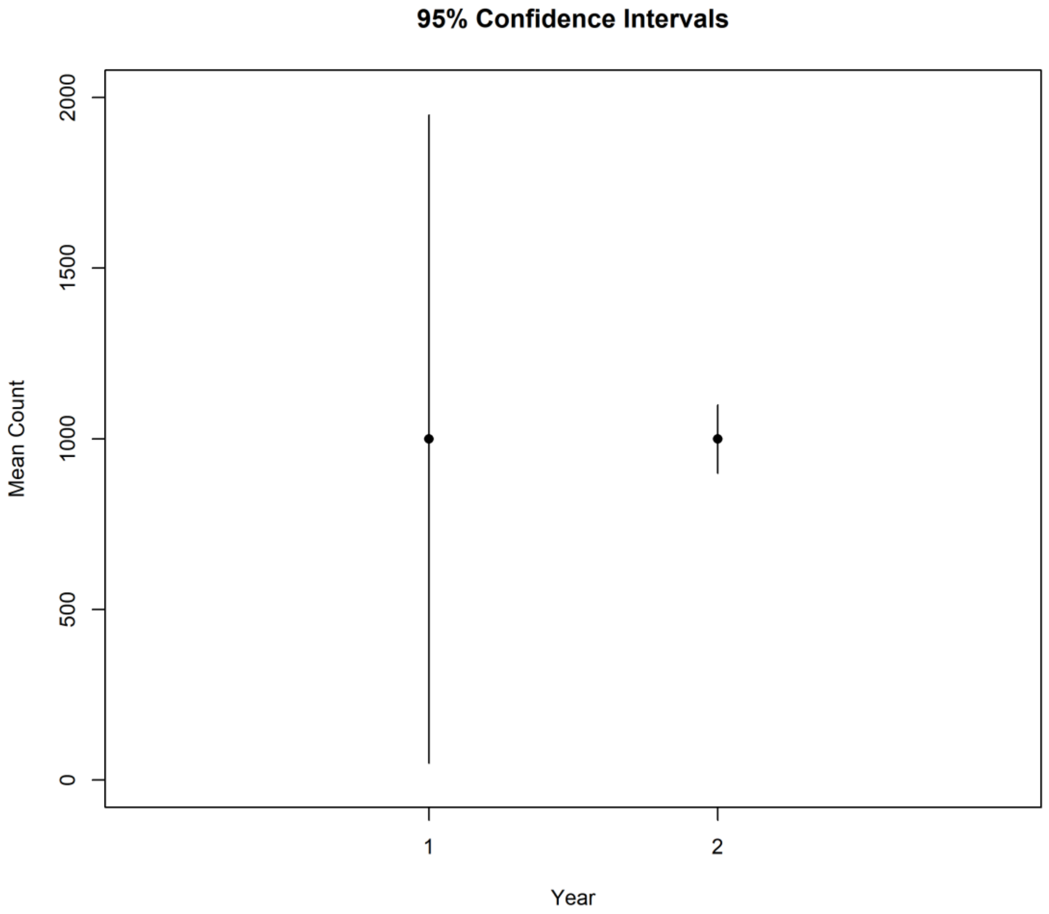
(5% Chance True Mean is Not Included)

Low Reliability

Lower CI	Mean	Upper CI
50	1000	1950

High Reliability (High Precision)

Lower CI	Mean	Upper CI
900	1000	1100



If we want greater confidence that the interval covers the true value, ↑%, but we become less certain about true value

Assessing Reliability of Single Estimate

Mean

Lower: $\hat{\bar{y}} - t_{\alpha/2} \cdot \sqrt{\frac{N-n}{N} \cdot \frac{\hat{s}^2}{n}}$

Upper: $\hat{\bar{y}} + t_{\alpha/2} \cdot \sqrt{\frac{N-n}{N} \cdot \frac{\hat{s}^2}{n}}$

Total

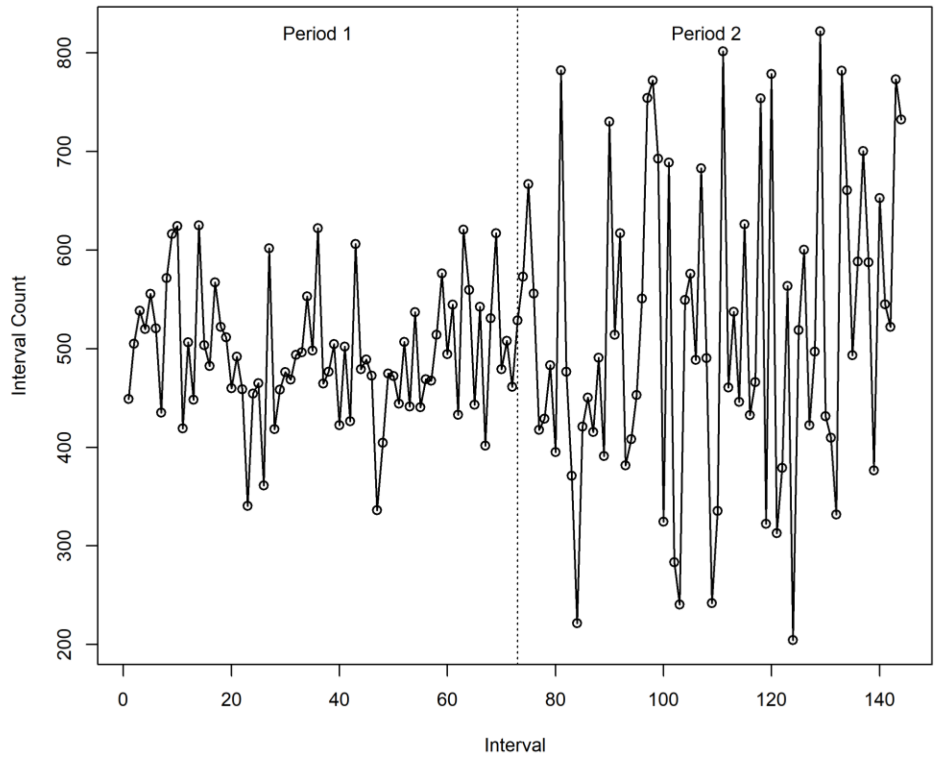
$\hat{Y} - t_{\alpha/2} \cdot \sqrt{N \cdot (N-n) \cdot \frac{\hat{s}^2}{n}}$

$\hat{Y} + t_{\alpha/2} \cdot \sqrt{N \cdot (N-n) \cdot \frac{\hat{s}^2}{n}}$

$$\hat{s}^2 = \frac{\sum_{i=1}^{n} (y_i - \hat{\bar{y}})^2}{n-1}$$

Must have min. 2 samples to calculate variance (should have > 2)

Sampling Designs



- Concerns every aspect of how data are selected
- Take advantage of consistent patterns in variability to increase precision of estimates
- Five designs discussed in Nelson (2006)
  - Recommended
  - Two-way stratified random sampling

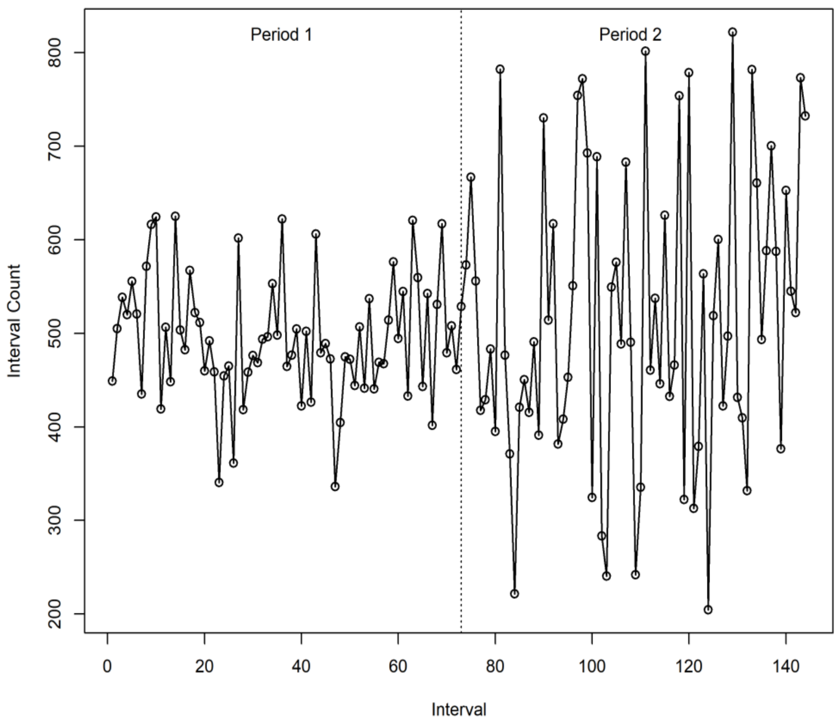
What Does Stratified Random Sampling Mean?

- Based on some factor that is linked to variability in observations, groups known as *strata* are created

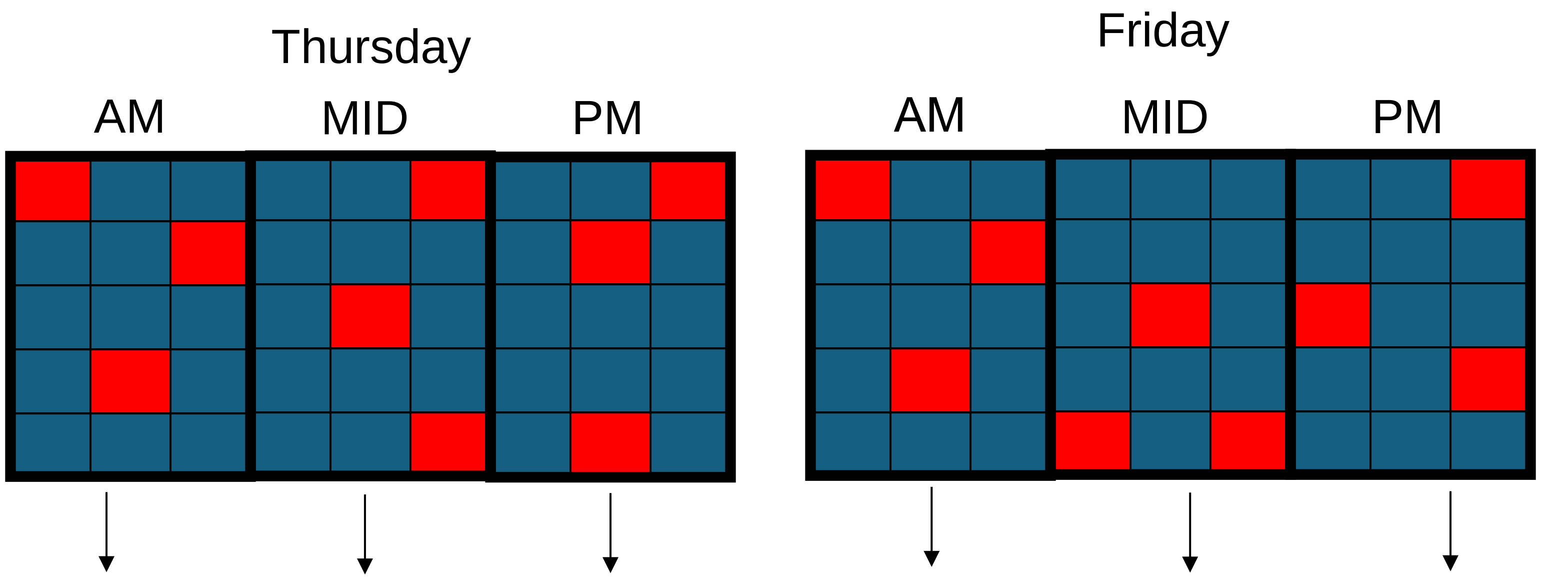
- Units within a stratum are picked at random

- Estimates of mean or total are made for each stratum and then are combined

- By making observations more homogeneous within a stratum, precision can be increased (CIs narrower)



Two-Way Stratified Random Sampling



$\hat{Y}_{T,1} = \hat{\bar{y}}_{T,1} \cdot N_{T,1}$

$\hat{Y}_{T,2} = \hat{\bar{y}}_{T,2} \cdot N_{T,2}$

$\hat{Y}_{T,3} = \hat{\bar{y}}_{T,3} \cdot N_{T,3}$

$\hat{Y}_{F,1} = \hat{\bar{y}}_{F,1} \cdot N_{F,1}$

$\hat{Y}_{F,2} = \hat{\bar{y}}_{F,2} \cdot N_{F,2}$

$\hat{Y}_{F,3} = \hat{\bar{y}}_{F,3} \cdot N_{F,3}$

Counting Period: 7 am to 7 pm

Counting Subperiods:
7-11 am, 11 am-3 pm, 3-7 pm

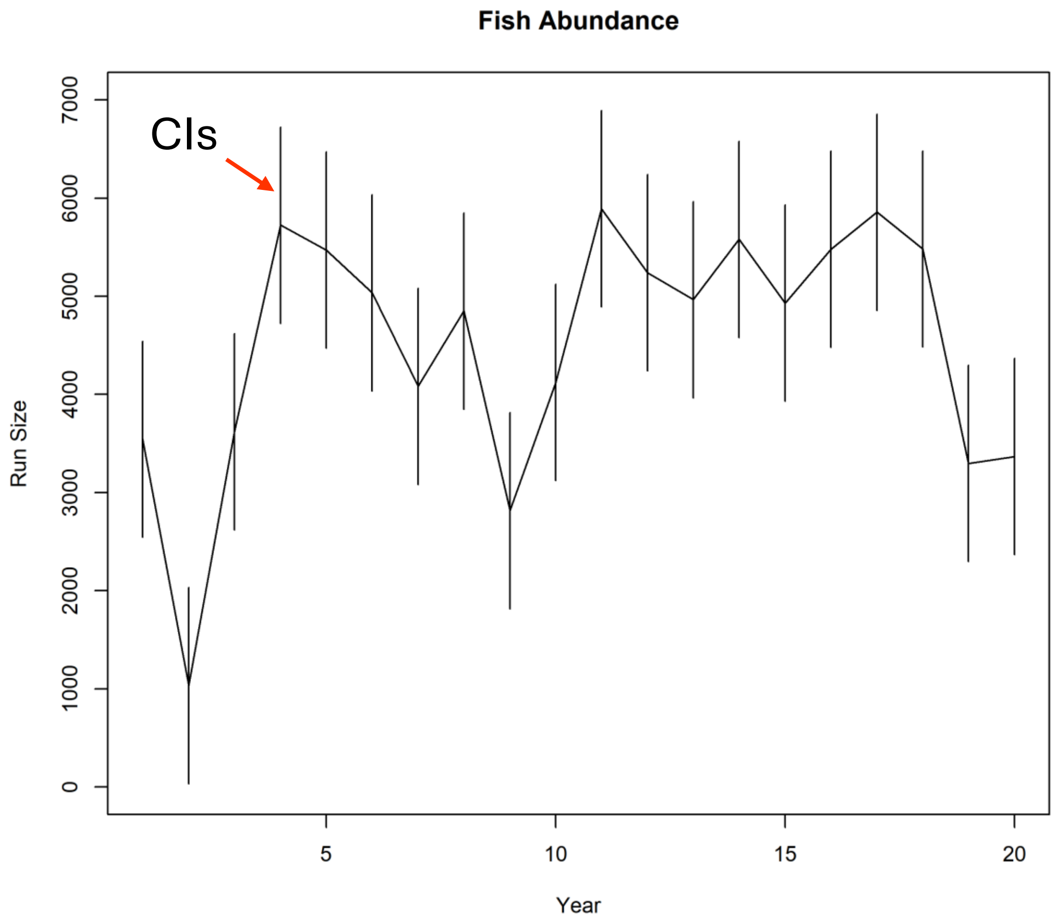
Counting Interval: 10 minutes

Counting Coverage:
3 counts per subperiod

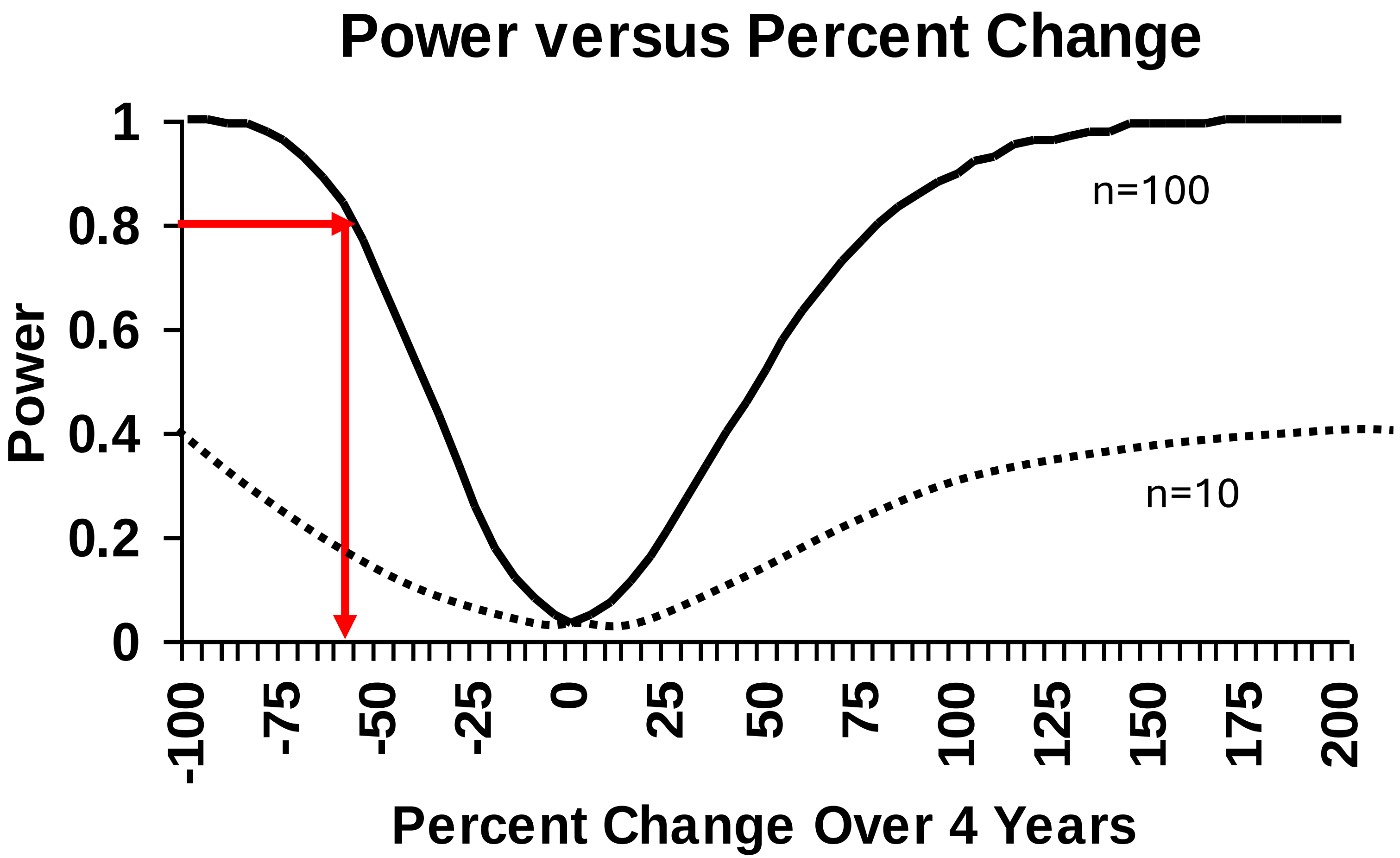
Daily Run Size = $Y_1+Y_2+Y_3$

Total Run Size = $Y_{T,1}+Y_{T,2}+Y_{T,3}+Y_{F,1}+Y_{F,2}+Y_{F,3}$

Power



- The ability to detect changes in run size over time when change is occurring is known as *power*
- The ability to statistically say that there is a change depends on the precision of estimate (and *n*)
- If run size is imprecisely estimated each year, may not conclude statistically that an observed increase or decrease in estimate is occurring
- But may be able to detect changes over several years



Gerrodette (1987; 1991) – many different assumptions from which to choose – see R fishmethods package, *powertrend*

What if the Sampling Procedures Aren't Followed

Three deficiencies that seriously affect the accuracy and precision of run size estimates

- Low sample sizes
- Non-random sampling
- Only counting when observe fish
- Unsampled days

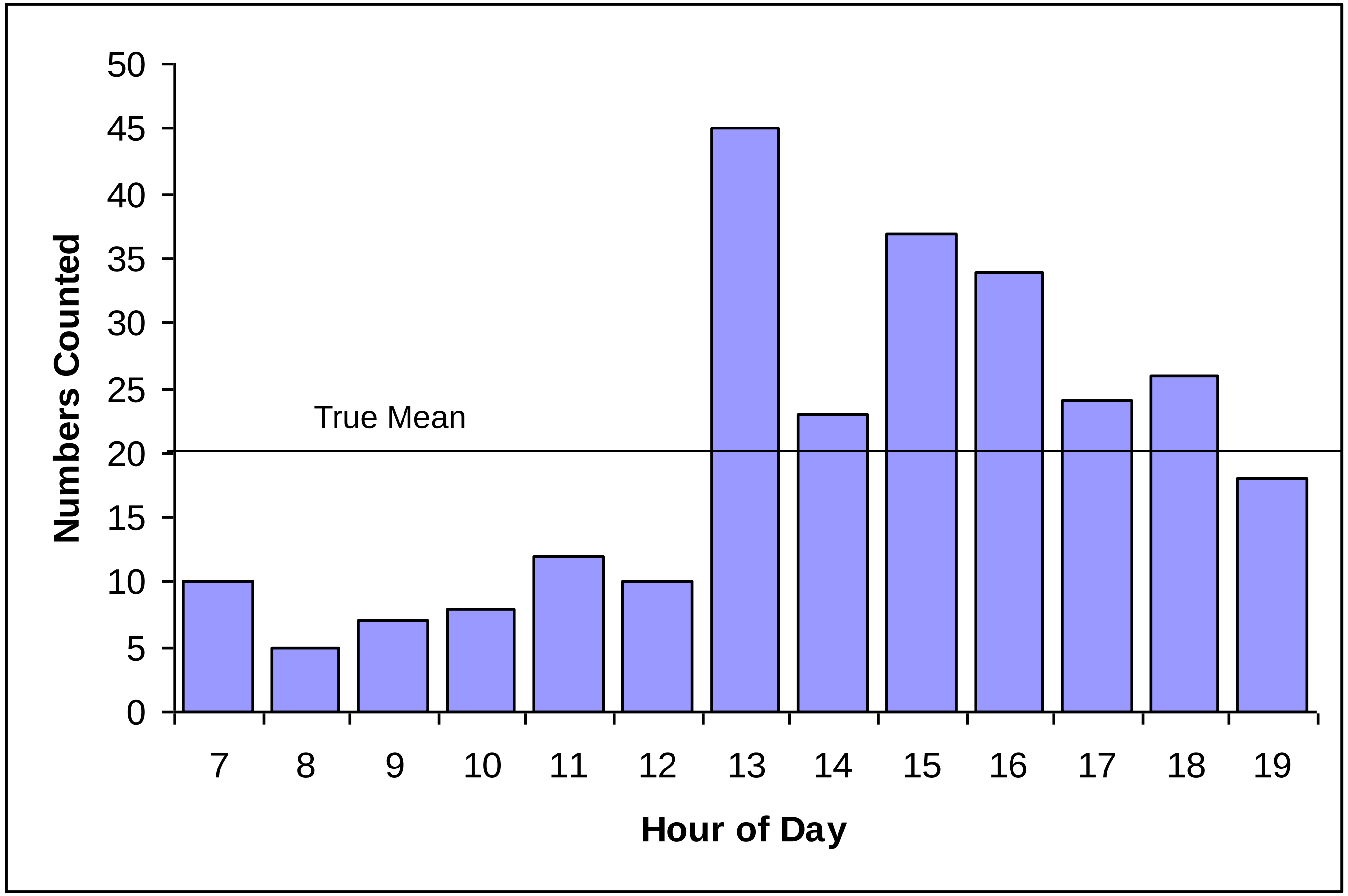
Low Sample Sizes

- Low sample sizes, low precision unless natural variation is very low
- Minimum of 2 required per stratum for all designs
- If only one sample, can't calculate sample variance which means confidence intervals will be underestimated
- Could make erroneous conclusion of the state of the run

Non-Random Sampling

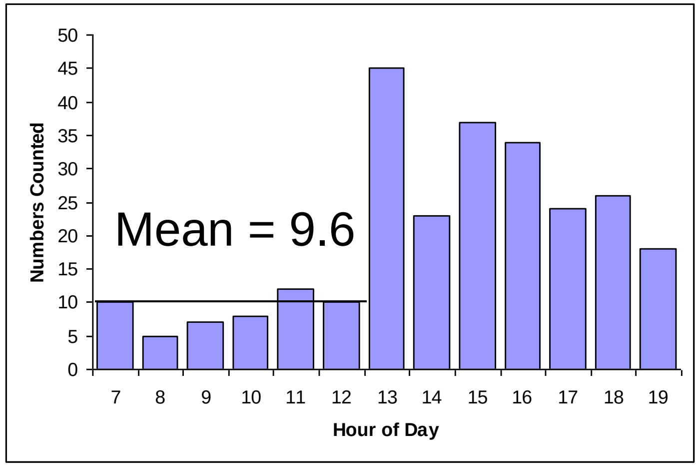
- Estimation theory is dependent on random selection of units
- Subjective selection biases estimates
  - Making contiguous counts for convenience
  - Counting the same time each day
- If patterns in fish migration, departures from random can have big impact on accuracy of estimate

Afternoon Migration



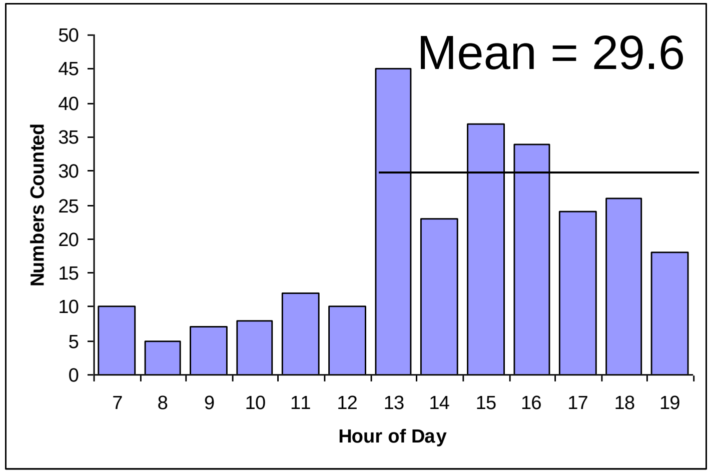
Total = 259

Morning Sampling Only



Total=124.8

Afternoon Sampling Only

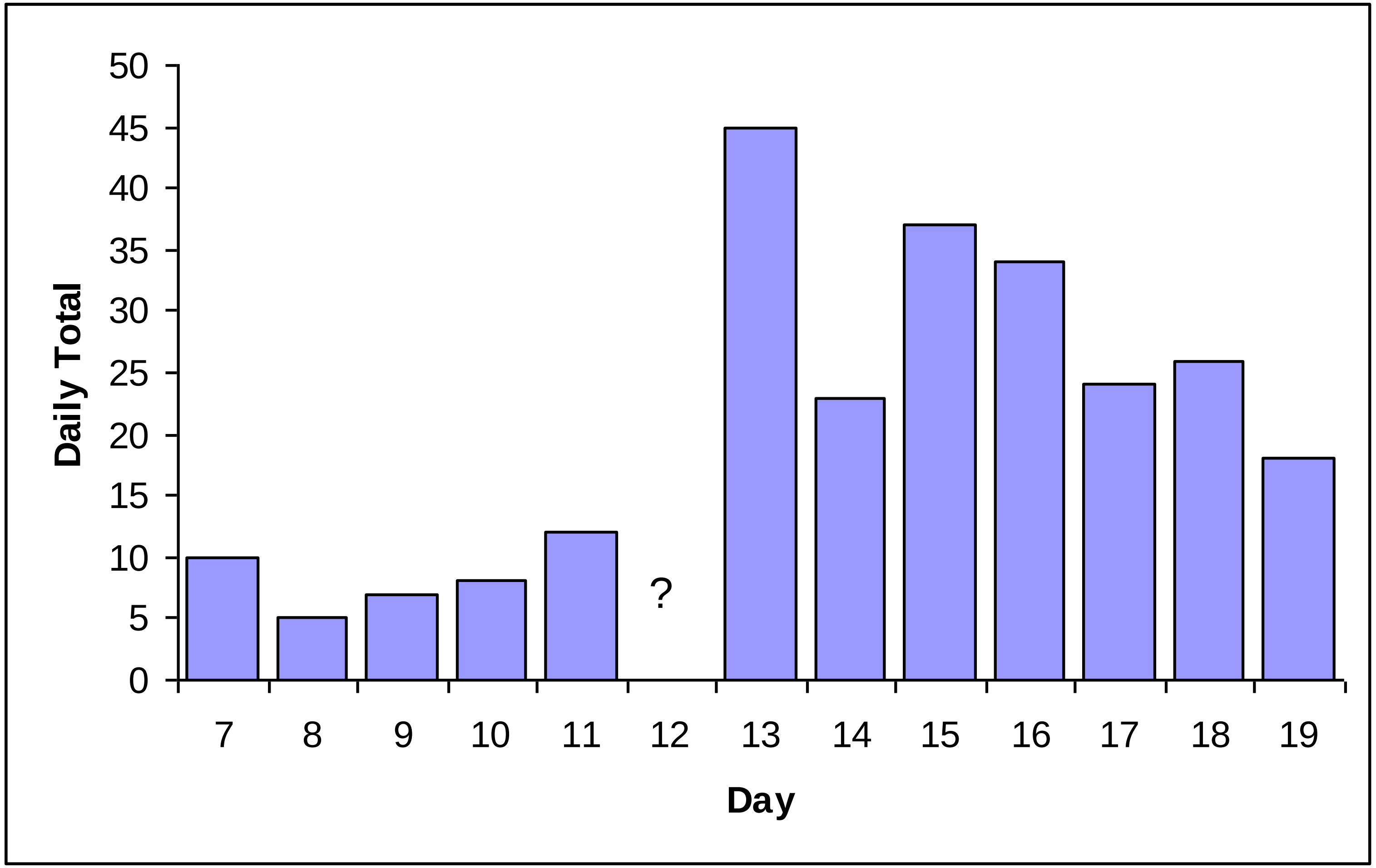


Total=384.8

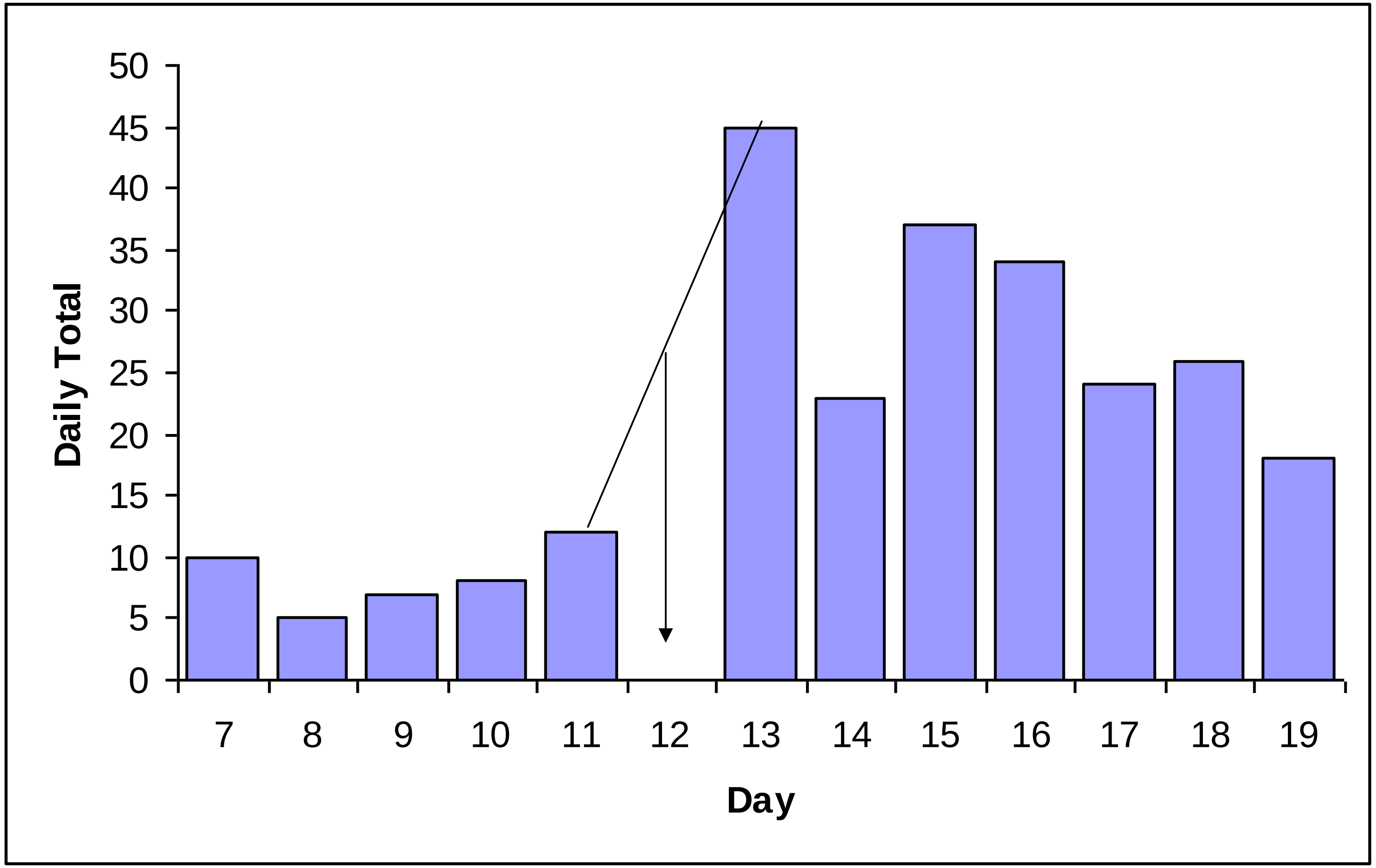
Only counting when fish are present

Zeros are important!!!!

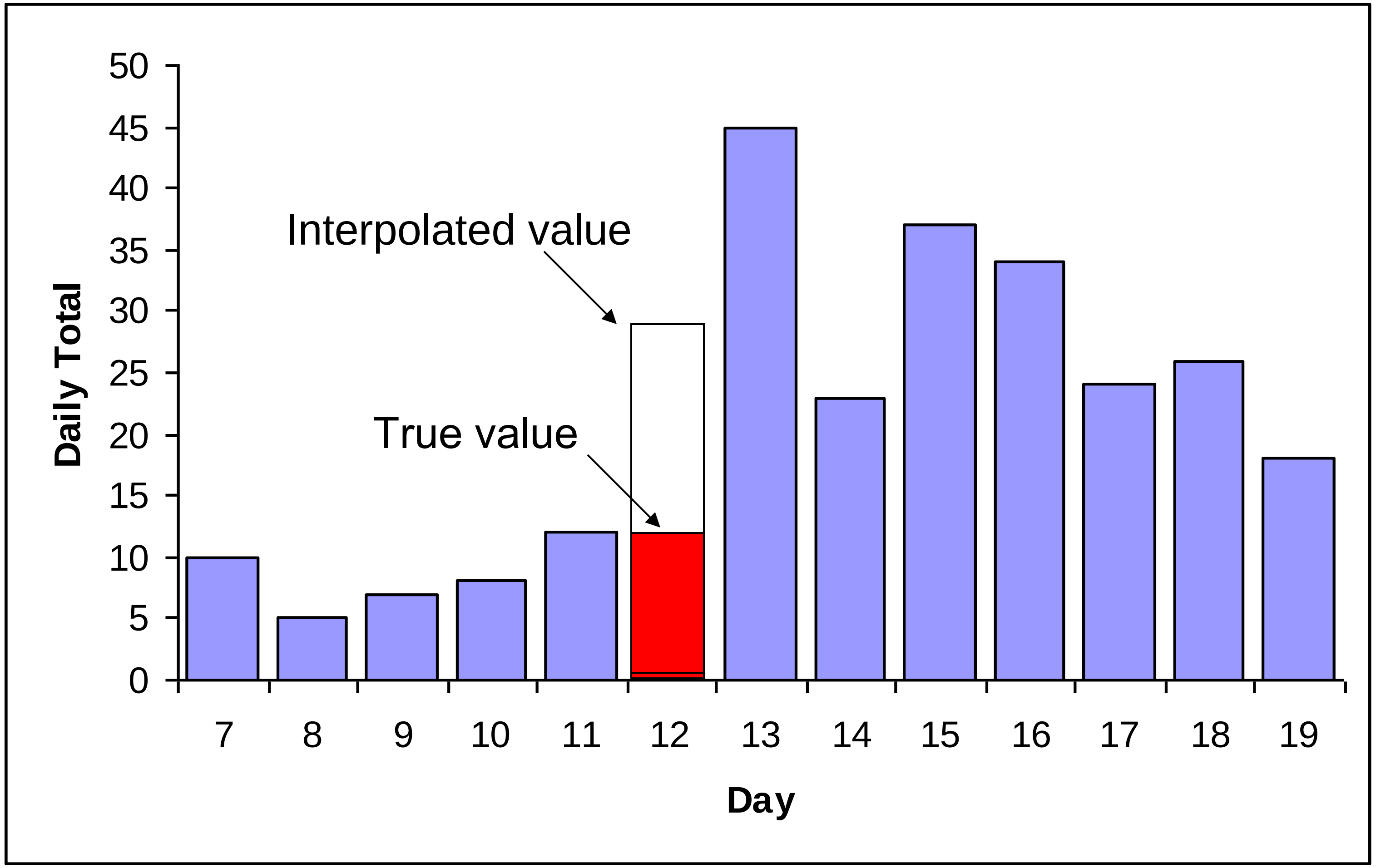
Interpolation of Missing Days



Interpolation of Missing Days



Interpolation of Missing Days



Interpolation of Missing Days

- Bias in run size as number of missing days increases

- Bias in run size as number sequential missing days increases

Other Issues

- Variable count interval length
  - Interval must be constant
- Back-to-back counts
  - Not randomly selected
- Intervals concentrated at same times each day
  - Not randomly selected
- Incorrect species identification
  - More than just river herring migrating
  - Need to properly train volunteers

Main Message

- To obtain unbiased estimates: randomly select units
- To obtain accuracy/precise estimates: increase sample size
- Deviations from theory affect estimates