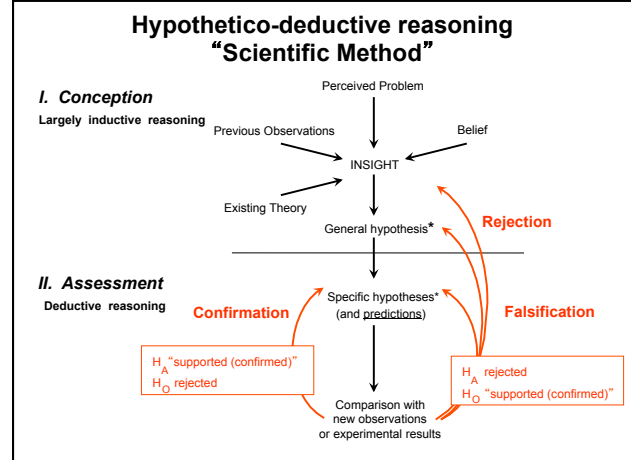


I. Statistics & Philosophy of Science

II. Approaches to Ecology

- Experiments vs. Observational Studies
- Empirical vs. Theoretical
- Basic Experimental Design



Is rigorous science based on *absolutes* or *probabilities*?

⇒ Reconciling Popperian science and statistical analysis

**Much of science is based on measured differences**

- A) Philosophical underpinnings of Popperian Method are based on absolute differences  
(E.g., All swans are white, therefore the next swan I see will be white. If the next swan is not white, then **the hypothesis is refuted absolutely.**)
- B) Most results, however, are based on comparisons of measured variables  
-- not really true vs. false, but the **degree** to which an effect exists  
-- e.g., predation causes there to be few prey in areas with many predators

*Example:*

**General or working hypothesis** – larval settlement determines adult distribution

**Specific hypothesis** – adult mussels should be more abundant where mussel larvae settle in higher numbers

Test: compare adult abundance in areas where many larvae settle versus areas where few larvae settle

Observation 1: Adult Abundance		Observation 2: Adult Abundance	
Low Settler Area	Abundant Settler Area	Low Settler Area	Abundant Settler Area
0	10	3	10
0	15	5	7
0	18	2	9
0	12	8	12
0	13	7	8
Mean 0	13	Mean 5	9.2

What counts as a difference?  
Are these different?



**Statistical Analysis**

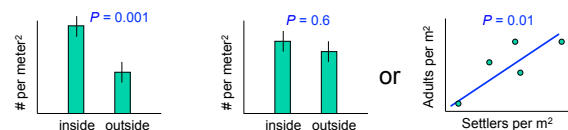
⇒ Used to quantify our certainty about the results of our hypothesis tests

Examples:

- Are two sets of values really different?
- Are two sets of measurements related to each other?

Statistical tests tell us the probability that our results are caused by chance

— the smaller that probability, the less likely our results are due to chance

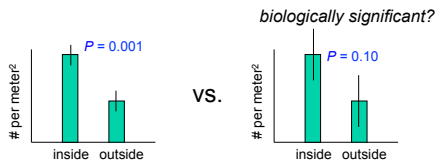


## Statistical Analysis: *p*-values

*P*-value  $\Rightarrow$  the probability that difference(s) or association found is caused by random chance

*P* = 0.05  $\Rightarrow$  usual cutoff for statistical significance  
(arbitrary but widely accepted convention)

**Don't confuse statistical significance with biological significance!**



## The statistical approach creates a problem for the Popperian (falsificationist) approach to science

- allows the possibility (e.g.,  $P = 0.05$ ) that a hypothesis has not truly been disproven (e.g., 5% chance hypothesis is true)
- strictly speaking, we can never falsify and reject hypotheses

- We live in a probabilistic world
- Little can ever be known with absolute certainty

## II. Approaches to Ecology

- Theoretical Ecology
- Empirical Ecology

### Empirical Ecology

- direct measurements of nature
- (observations & experiments to develop and test hypotheses)



### Theoretical Ecology

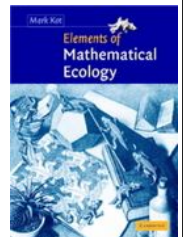
- verbal or *mathematical models* of nature
- no measurements made in nature



- historically Theoretical and Empirical ecologists have worked independently
- less separation today
  - many ecologists do both
  - many ecologists collaborate
- combining the two approaches is powerful

### Theoretical Ecology:

- systems of mathematical equations to deduce how nature works
- processes (e.g., population growth) described by equations, and parameters (e.g., death rate) in models varied to examine their effect
- two main approaches:
  - Analytic
  - Simulation



## Analytic

- vastly simplified representation of nature
- divorced from the biology of any particular organism
- used to explore general questions  
(e.g., in what ways can predators affect prey population dynamics?)
- results are intended to be general -- should apply to many species

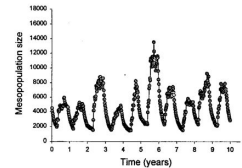
Example: Lotka-Volterra predator-prey model

$dx/dt = \alpha x - \beta xy$  prey population growth

$dy/dt = \delta xy - \gamma y$  predator population growth

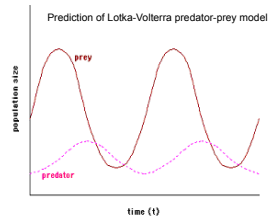
## Simulation

- used to explore specific situations  
(e.g., effects of *Pisaster* predation on mussel beds)
- usually very complex sets of equations
- include much biological realism
- only directly apply to situation modeled
- provide insight into situations impossible to study in field  
(e.g., too large or would take too long)



## Strengths of Theoretical Ecology

- simplicity can lead to generality
- clarifies possible (& impossible) cause-&-effect relationships (e.g., disprove verbal theories)
- allows study of questions that are logistically impossible to study in the field

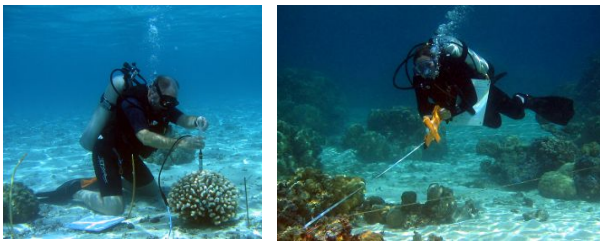


## Weaknesses of Theoretical Ecology

- oversimplification of nature required
  - simplifying assumptions (which are seldom true) must be made to make tractable models
  - these assumptions can distort nature
- predictions are often untestable or untested empirically

## Empirical Ecology

- has dominated Marine Ecology
- two general types:
  - **Experimental**
  - **Observational (Mensurative)**



## Empirical Ecology

### Experimental vs. Observational

What distinguishes an experiment from an observational study?

- an experiment always involves a manipulation
- observational studies only involve measurements

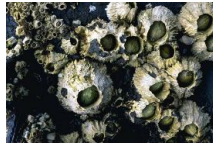
Experiments involve more work, so why do them?

- Can clearly **demonstrate causal relationships**

## Experimental Ecology



- Popularized by Joe Connell (UCSB) in 1960' s
- Weakness: limited in spatial and temporal scale
- Two types:
  - Lab Experiment
  - Field Experiment



## Lab Experiments:

strength: good control of external variation

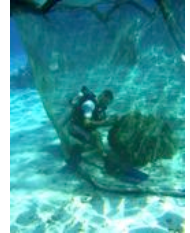
weakness: lack realism



## Field Experiments:

strength: realistic

weakness: difficult to control extraneous variation



## Key elements of a good experiment

- 1. Control:** an experimental unit that is identical to the treatment in every way, except that the manipulation has not been done
- 2. Replication:** use of identical experimental units (both treatment & control)
  - often limited in field experiments
  - measures natural variability – gives context
- 3. Statistical Analysis:** used to separate meaningful results from happenstance

*“Natural Experiments”* are not proper experiments -- lack proper design (treatments & controls not assigned randomly; not replicated)

## Comparison of Empirical Techniques in Ecology

Factor	Lab Experiment	Field Experiment	Observational Study
1. Control of Variation	Highest	Medium/Low	None
2. Replicate Matching	Highest	Medium	Medium/Low
3. Temporal Scale	Lowest	Low/Medium	Highest
4. Spatial Scale	Lowest	Low/Medium	Highest
5. Realism	Low	High	Highest
6. Generality	Low	Low/Medium	Highest