Scientific Inquiry

How do we "do science" ?

Observations → Question → "Inquiry Cycle" → Actions → Reflection → Observations

Actions:
- Hypotheses
- Study design
- Research
- Data analysis

Reflection:
- Conclusions
- Applications
- Further questions

Scientific Inquiry

OBSERVATION-DRIVEN SCIENCE

Observations → Question → "Inquiry Cycle" → Actions → Reflection → Observations

Actions:
- Hypotheses
- Study design
- Research
- Data analysis

Reflection:
- Conclusions
- Applications
- Further questions

Scientific Inquiry

THEORY-DRIVEN SCIENCE

~~Observations~~ Theory → Question → "Inquiry Cycle" → Actions → Reflection → Observations

Actions:
- Hypotheses
- Study design
- Research
- Data analysis

Reflection:
- Conclusions
- Applications
- Further questions

Scientific Inquiry

Observations → Question → "Inquiry Cycle" → Actions → Reflection → Observations

What makes a "good" scientific question ?

Actions:
- Hypotheses
- Study design
- Research
- Data analysis

Reflection:
- Conclusions
- Applications
- Further questions

Scientific Inquiry

Four Criteria for "good" scientific questions from the electronic reserve reading

1.

2.

3.

4.

Scientific Inquiry

A "good" scientific question must be "answerable"

1.

2.

3.

"How", "how many", "which" questions often feasible

Simple: How many Douglas-fir trees live in the wetland?

Comparative: How many DF trees live in the wetland compared to the hillside?

Simple: Which birds use old cedar snags as perches?

Comparative: Which birds use cedar snags as compared to maple snags?

Scientific Inquiry

A "good" scientific question must be "answerable"

1.

2. *List from previous slide*

3.

"How", "how many", "which" questions often feasible

"Why" questions often are too complex (rarely with single answers)

HOWEVER, "why" questions are excellent starting places for the creation of testable questions!

Example:

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Often, a "good" scientific question is comparative*

1. Comparisons often create broader, more interesting implications and deeper learning.

Absolute: What is the density of mountain goats living above 6,000 feet in the Olympic Mountains?

Comparative: Is there a difference in the density of mountain goats living above 6,000 in the Olympic Mountains versus the Cascade Mountains?

Absolute: What factors affect the rate of berry ripening?

Comparative: Do berries ripen more quickly in the sun or in the shade?

* Not always!

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Often, a "good" scientific question is comparative

2. Comparisons must have a meaningful basis (in prior knowledge or common sense)

Good: Are ants more numerous in nests in sunny locations or in nests in shaded locations?

Poor: Are ants more numerous in nests near houses where people watch Public Television or near houses where people watch HBO?

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A "good" scientific question should be

INTERESTING

TANTALIZING

FASCINATING

ABSORBING

ETC.

TO WHOM?

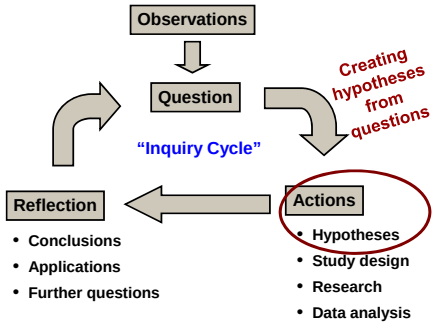
Scientific Inquiry

A "good" scientific question should be able to be stated in a straight-forward manner

Jargon has its role, but not in the stating of the basic question(s) to be addressed!

If one cannot state the question simply then it is possible one doesn't fully understand what is being asked

Scientific Inquiry



Scientific Inquiry

Creating Hypotheses

Simple questions usually lead to a singular, testable hypothesis

Question:

Do berries ripen more quickly in the sun or in the shade?

Hypothesis:

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Creating Hypotheses

"Why" questions usually lead to multiple, "alternative" hypotheses

Why do trees grow on ridges at high elevation?

Hypotheses:

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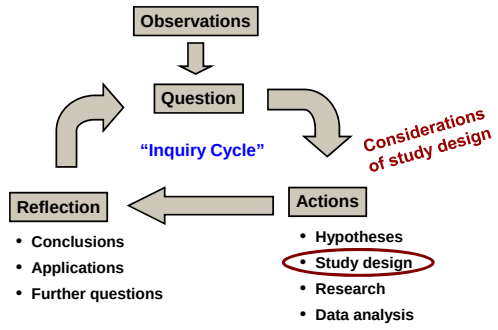

Scientific Inquiry

Study Design

Reliability & validity in the design of scientific studies

Reliability: **Validity:**

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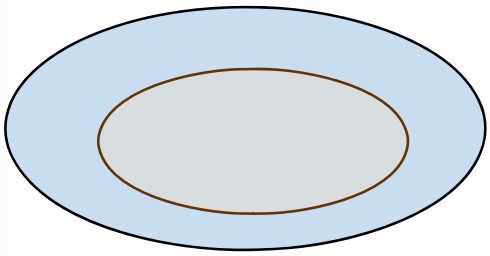
Study Design

Reliability & validity in the design of scientific studies

Reliability: **Validity:**



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Study Design

Reliability & validity in the design of scientific studies

EXAMPLE

Question Does increased exposure to methyl bromide increase the incidence of cancer ?

Study Record cancer rates in populations near industries that use different amounts of methyl bromide

See following slide for schematic decision tree to decide on the reliability & validity of this study

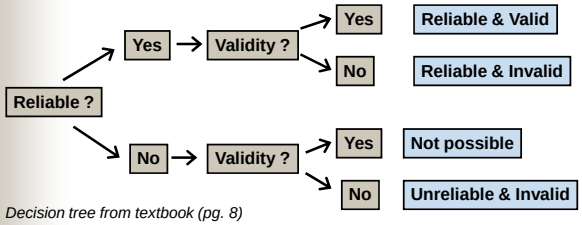
Scientific Inquiry

Study Design

Reliability & Validity

Question Does increased exposure to methyl bromide increase the incidence of cancer ?

Study Record cancer rates in populations near industries that use different amounts of methyl bromide



Decision tree from textbook (pg. 8)

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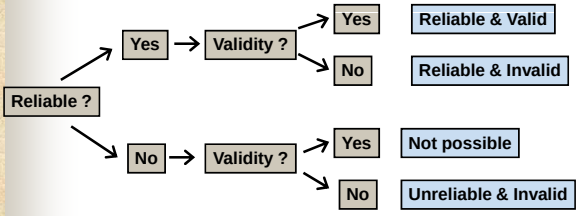
Study Design

Reliability & validity in the design of scientific studies

Question: What are the habitat limits for grey whales?

Study: GPS transceiver attached to one migrating grey whale, allowing continuous tracking of movements.



Decision tree from textbook (pg. 8)

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Study Design

Dependent & Independent Variables

Question: What influences the success of plants in our campus wetland restoration?

Dependent variable?

Independent variables?

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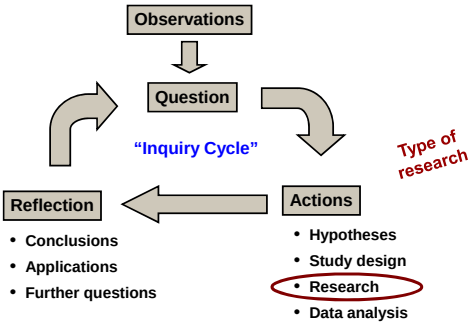

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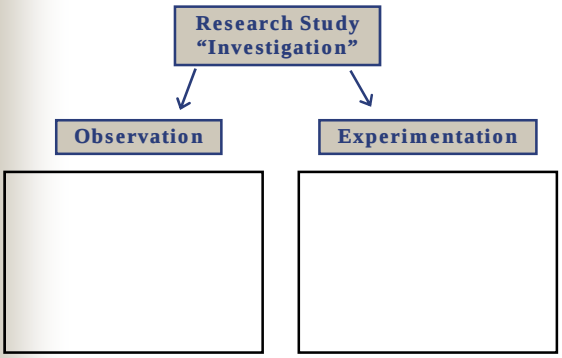
Research



Scientific Inquiry

Observation vs. Experimentation – an example

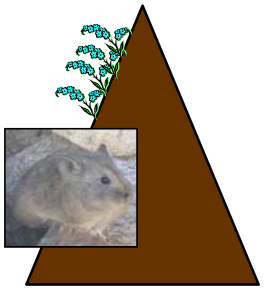
Observation:
Alpine speedwell grows only above 10,000 feet in the Rockies

↓

Question:
Why does alpine speedwell grow only above 10,000 feet in the Rockies?

↓

Hypothesis:
Pikas consume alpine speedwell seeds below 10,000 feet - preventing their regeneration.



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Observation vs. Experimentation – an example

Hypothesis:
Pikas consume alpine speedwell seeds below 10,000 feet preventing their regeneration.

Observational Approaches:

Experimentation Approaches:

Scientific Inquiry

Research

Observation or Experiment ?

- Rancher Smith's pet coyote got loose and ate every pika in the entire valley.
- You take advantage of this and record alpine speedwell plant demography above and below 10,000 feet in the coming years.

Is your study observation or experimentation?

↓

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Research

Considerations about Observation & Experimentation

Research Study

Observation

Considerations

- Difficult to isolate factors & determine causation in complex systems
- Observations colored by cultural & educational biases
- Heisenberg uncertainty principle

Experimentation

Considerations

- Can take factors out of their natural context – altering their impact on the system – and alter the system in complex & unexpected ways

Scientific Inquiry

Determining causation: observational & experimental approaches

Question:
Why does dogwood only grow low on slopes?

Observation:
Dogwood only grows low down on slopes

↓

Hypothesis:
A lack of moisture higher on slopes limits dogwood success.

Scientific Inquiry

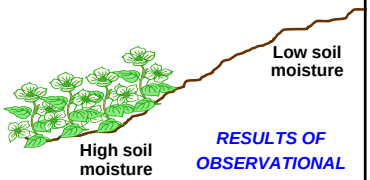
Determining causation: observational & experimental approaches

Question:
Why does dogwood only grow low on slopes?

Have we PROVED that a lack of soil moisture restricts dogwood from growing higher?

↓

Hypothesis:
A lack of moisture higher on slopes limits dogwood success.



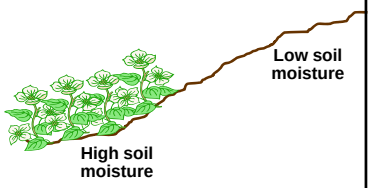
RESULTS OF OBSERVATIONAL STUDY

Scientific Inquiry

Determining causation: observational & experimental approaches

Question:
Why does dogwood only grow low on slopes?

Hypothesis:
A lack of moisture higher on slopes limits dogwood success.

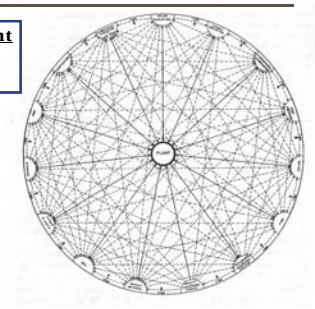


Scientific Inquiry

Research

The **Holocoenotic Environment** and Pitfalls of Experimentation in Natural Ecosystems

Holocoenotic Environment
Introducing two important aspects of ecological systems



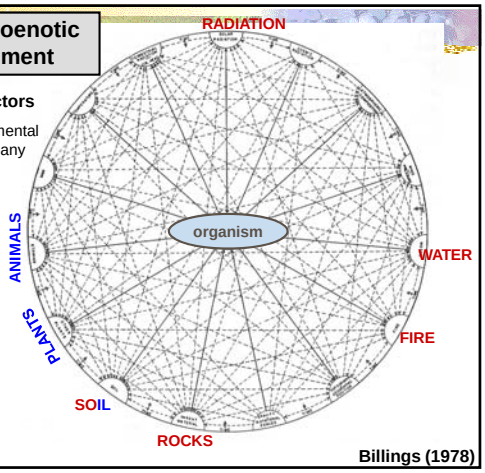
The Holocoenotic Environment

1. Mulitple Factors

Multiple environmental factors influence any organism.

2. Factor Interaction

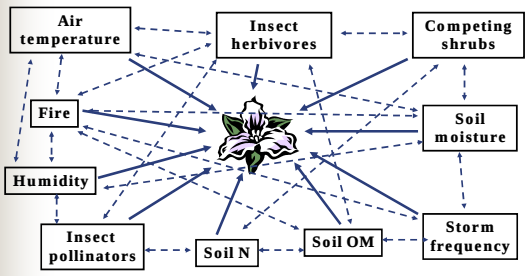
These multiple factors interact in variable and complex ways through space & time.



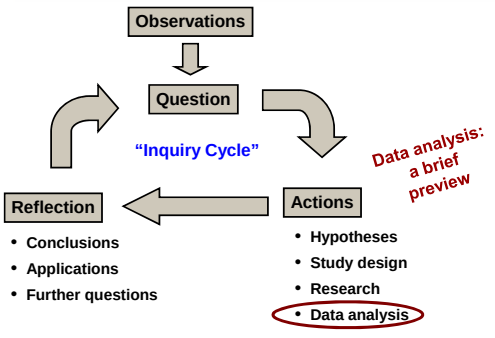
Billings (1978)

Scientific Inquiry

The Holocoenotic Environment and Pitfalls of Experimentation in Natural Ecosystems



Scientific Inquiry



- Conclusions
- Applications
- Further questions

- Hypotheses
- Study design
- Research
- Data analysis

The implications of scientific results: Correlation and causation

Scientific Inquiry

Data Analysis

Correlation and Causation: What can we prove?

Observation:
Trees occur in ribbons along the crest of ridges and are absent in the gullies in between the ridges.

Hypothesis:

Scientific Inquiry

Data Analysis

Correlation and Causation: What can we prove?

Results:

	Gullies	Ridges
# Trees / m^2	0.06	0.90
# Avalanches / year	4.2	0.3

Do these data support the hypothesis?

Conclusion:

Scientific Inquiry

Correlation and Causation: What can we prove?

What if we had some additional data?

What causes tree ribbons?
What do we "know"?

Results:

	Gullies	Ridges
# Trees / m^2	0.06	0.90
# Avalanches / year	4.2	0.3
Soil depth (cm)	8.1	56.4
5 cm mean air temp. (°C)	4.5	10.8

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Correlation and Causation: What can we prove?

Comparing different results

Results:

	Gullies	Ridges
# Trees / m^2	0.06	0.90
# Avalanches / year	4.2	0.3

Conclusion:

Results:

	Gullies	Ridges
# Trees / m^2	0.06	0.90
# Avalanches / year	1.2	1.2

Conclusion:

Which is the most conclusive conclusion?

Scientific Inquiry

Correlation and Causation: What can we prove?

Comparing different results

Results:

	Gullies	Ridges
# Trees / m^2	0.06	0.90
# Avalanches / year	4.2	0.3

Hypothesis is _____

Results:

	Gullies	Ridges
# Trees / m^2	0.06	0.90
# Avalanches / year	1.2	1.2

Hypothesis is _____

Hypotheses CANNOT BE _____

they can only be _____

Scientific Inquiry

Data Analysis

If we can only DISPROVE hypotheses, how do we proceed?

The multiple alternative hypotheses approach

- Develop multiple alternative hypotheses for the question.
- Test each hypothesis.
- Discard hypotheses that are disproven.
- As you disprove more alternatives, the support for the remaining hypothesis (or hypotheses) increases.
- With time, as a hypothesis continues to be supported by results and failed to be disproved it attains the status of a theory (and perhaps eventually a "law").

Scientific Inquiry

Data Analysis

The multiple alternative hypotheses approach

Results:

	Gullies	Ridges
# Trees / m^2	0.06 a	0.90 b
# Avalanches / year	4.2 a	0.3 b
Soil depth (cm)	8.1 a	9.4 a
Pine seeds cached / m^2	0.6 a	264.0 b
Soil moisture (%)	32.6 a	29.8 a
5 cm mean air temp. (°C)	4.5 a	10.8 b

What do we know from these results?

Hypotheses disproven:

Hypotheses supported:

Scientific Inquiry

Data Analysis

The multiple alternative hypotheses approach

Results:

	Gullies	Ridges
# Trees / m^2	0.06 a	0.90 b
# Avalanches / year	4.2 a	0.3 b
Soil depth (cm)	8.1 a	9.4 a
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5 cm mean air temp. (°C)	4.5 a	10.8 b

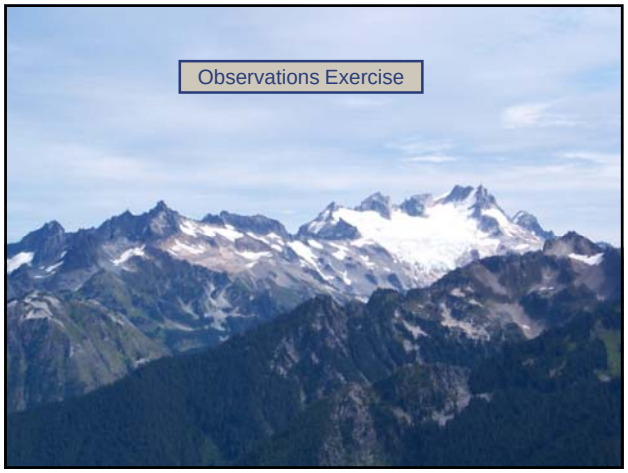
The Difficulty of Assigning Causation in Ecology

Multiple causal factors are not unusual in ecological systems (unlike many other sciences).

A combined approach of observational studies and experimental studies are often the most powerful way to elucidate a complex web of causation.

Scientific Inquiry: a synopsis of today's material

1. Scientific inquiry as a cycle
2. Scientific questions
3. Hypotheses
4. Study design
   - Validity & reliability
   - Dependent & independent variables
5. Research: Observation & Experimentation
   - The nature & considerations of the two approaches
   - Complex natural systems create challenges for experiments
6. Data analysis: Correlation vs. Causation
   - Proof & disproof
   - Multiple alternative hypotheses approach



Pattern & Process

Linking PATTERN and PROCESS

Scientists assume these patterns have some understandable basis; that the world is not governed by chance.

Exploring the link between pattern and underlying process will reveal something about how nature works.

Observations Exercise

Step 1: Make observations of NATURAL phenomena in natural areas on campus (*some class time available Oct 7 &12*)

Observations

Look at different spatial scales and at different times

Observations

Don't just limit your observations to the VISUAL realm!

Observations Exercise

- 5 Observations in Natural Areas of campus
- Each observation with a question

Observation 1:
Question:
Observation 2:
Question:
Observation 3:
Question:
Observation 4:
Question:
Observation 5:
Question:

- Focus on phenomena not influenced by humans (or at least those with possible natural explanations)
- Focus on "How" and "Why" – type questions
- Questions you can conceivably test immediately
- Questions for which you can derive multiple alternative hypotheses

Observations Exercise

Identifying organisms

If you wish to put a name to any organisms you make observations on, sketch them, note important features, take a digital picture, and come ask me!

Observations Exercise

Step 2: Written Assignment

Due Monday (October 19) !!!

Part I

1. Observation 1:
   Observation Description:
   Question 1:
   Question Derivation: if necessary to explain how the question was derived from the observation
2. Observation 2:
   Observation Description:
   Question 2:
   Question Derivation:

And so on through all 5 observations

Example provided on page 3 of Observations Exercise Handout

Observations Exercise

Step 2: Written Assignment

Part II *for your top 2 questions ONLY*

1. Question 1:
   Why I chose this question:
   Hypothesis 1A:
   Hypothesis 1B:
   Hypothesis 1C:

   These are ALTERNATIVE hypotheses

2. Question 2:
   Why I chose this question:
   Hypothesis 2A:
   Hypothesis 2B:
   Hypothesis 2C: