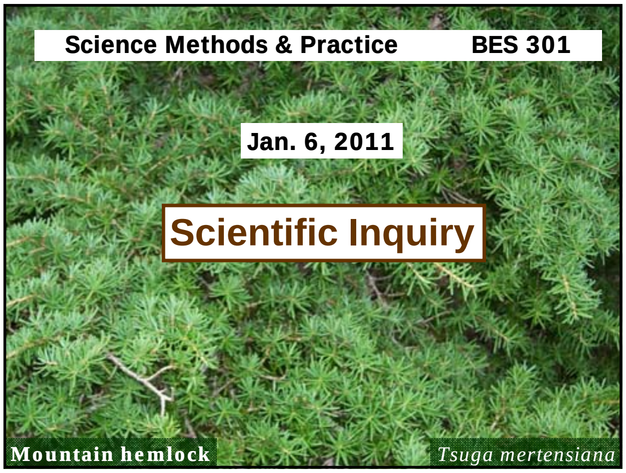


Scientific Inquiry

How do we "do science" ?

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

Reflection
- Conclusions
- Applications
- Further questions

Actions
- Hypotheses
- Study design
- Research
- Data analysis

Scientific Inquiry

OBSERVATION-DRIVEN SCIENCE

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

Reflection
- Conclusions
- Applications
- Further questions

Actions
- Hypotheses
- Study design
- Research
- Data analysis

Scientific Inquiry

THEORY-DRIVEN SCIENCE

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

Reflection
- Conclusions
- Applications
- Further questions

Actions
- Hypotheses
- Study design
- Research
- Data analysis

Scientific Inquiry

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

What makes a "good" scientific question ?

Reflection
- Conclusions
- Applications
- Further questions

Actions
- Hypotheses
- Study design
- Research
- Data analysis

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:

Scientific Inquiry

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!

Scientific Inquiry

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?

Scientific Inquiry

A "good" scientific question should be

INTERESTING

TANTALIZING

FASCINATING

ABSORBING

ETC.

TO WHOM?

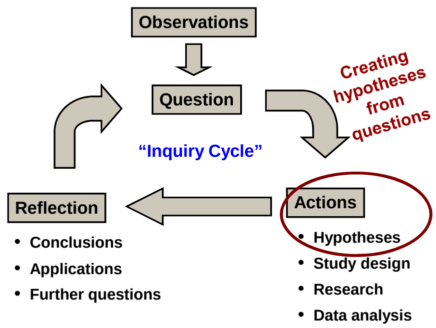
Scientific Inquiry

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:

Scientific Inquiry

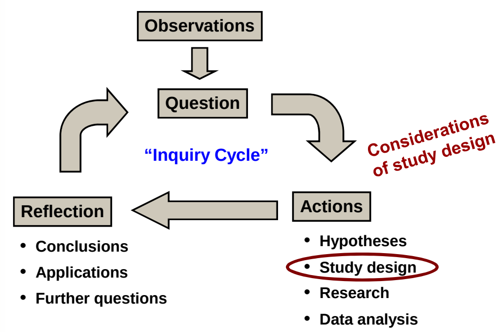
Creating Hypotheses

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

Why do trees grow on ridges at high elevation?

Hypotheses:

Scientific Inquiry



Scientific Inquiry

Study Design

Reliability & validity in the design of scientific studies

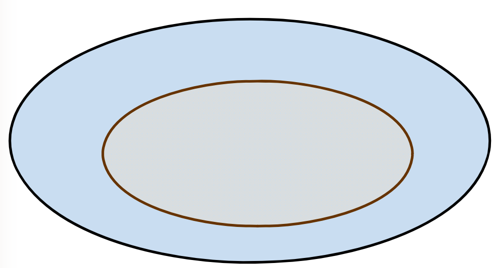
Reliability: **Validity:**

Scientific Inquiry

Study Design

Reliability & validity in the design of scientific studies

Reliability: **Validity:**



Scientific Inquiry

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

- Reliable ? → Yes → Validity ? → Yes → Reliable & Valid
- Reliable ? → Yes → Validity ? → No → Reliable & Invalid
- Reliable ? → No → Validity ? → Yes → Not possible
- Reliable ? → No → Validity ? → No → Unreliable & Invalid

Decision tree from textbook (pg. 8)

Scientific Inquiry

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.

- Reliable ? → Yes → Validity ? → Yes → Reliable & Valid
- Reliable ? → Yes → Validity ? → No → Reliable & Invalid
- Reliable ? → No → Validity ? → Yes → Not possible
- Reliable ? → No → Validity ? → No → Unreliable & Invalid

Decision tree from textbook (pg. 8)

Scientific Inquiry

Study Design

Dependent & Independent Variables

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

Dependent variable?

Independent variables?

Scientific Inquiry

Observations ⇩ Question

"Inquiry Cycle"

Type of research

Actions
- Hypotheses
- Study design
- Research
- Data analysis

Reflection
- Conclusions
- Applications
- Further questions

Scientific Inquiry

Research

Research Study "Investigation"

Observation | **Experimentation**

Scientific Inquiry

Observation vs. Experimentation – an example

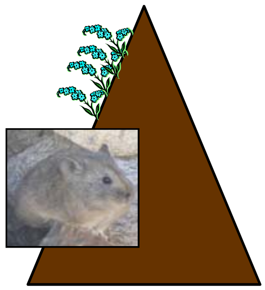
Observation:
Alpine speedwell grows only above 10,000 feet in the Rockies

↓

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.



Scientific Inquiry

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?

↓

Scientific Inquiry

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

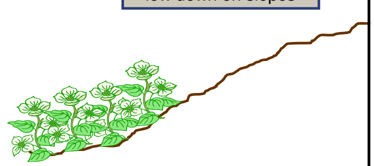
Determining causation: observational & experimental approaches

Question:
Why does dogwood only grow low on slopes?

↓

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

Observation:
Dogwood only grows low down on slopes



Scientific Inquiry

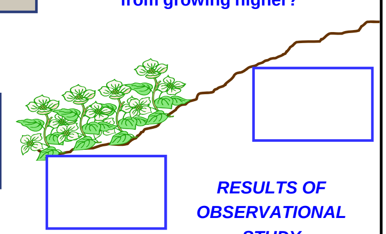
Determining causation: observational & experimental approaches

Question:
Why does dogwood only grow low on slopes?

↓

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

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



RESULTS OF OBSERVATIONAL STUDY

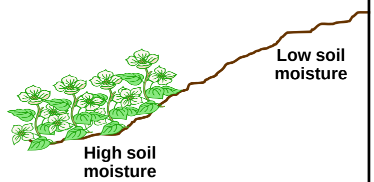
Scientific Inquiry

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.

How could we better test the <u>causal</u> effect of water?

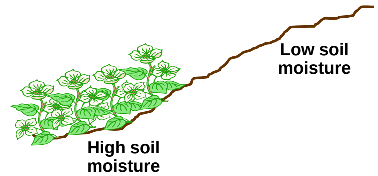


Scientific Inquiry

Experimentation in complex systems

Question:
Why does dogwood only grow low on slopes?

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

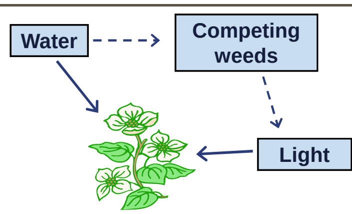


Scientific Inquiry

<u>Research</u>

The Holocoenotic Environment and Pitfalls of Experimentation in Natural Ecosystems

Changing one variable can have complex, interwoven effects

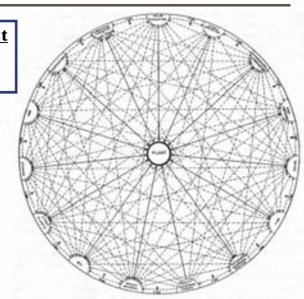


Scientific Inquiry

<u>Research</u>

The **<u>Holocoenotic Environment</u>** : recognizing the complexity of natural ecosystems

<u>Holocoenotic Environment</u>
Introducing two important aspects of ecological systems



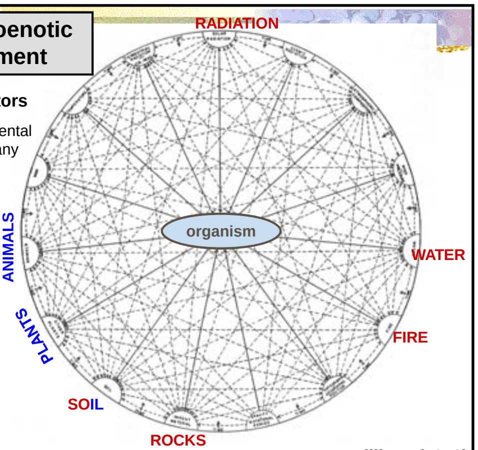
The Holocoenotic Environment

1. Mulitple Factors

Multiple environmental factors influence any organism.

2. Factor Interaction

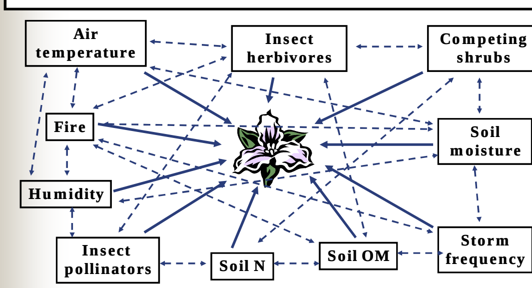
These multiple factors interact in variable and complex ways through space & time.



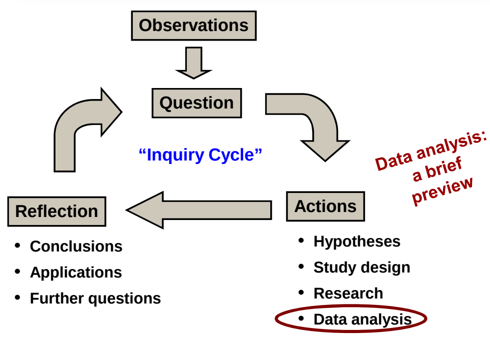
Billings (1978)

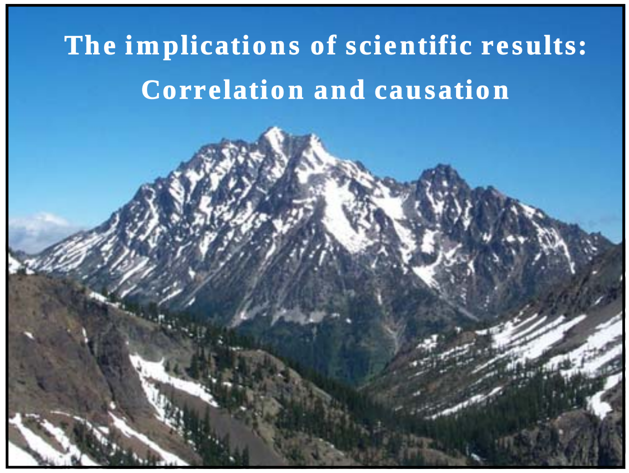
Scientific Inquiry

The Holocoenotic Environment



Scientific Inquiry





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 / m²	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 / m²	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

Scientific Inquiry

Correlation and Causation: What can we prove?

Comparing different results

Results:

	Gullies	Ridges
# Trees / m²	0.06	0.90
# Avalanches / year	4.2	0.3

Conclusion:

Results:

	Gullies	Ridges
# Trees / m²	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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Soil moisture (%)	32.6 a	29.8 a
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