Today

- Study design
- Wednesday
  - precorded lecture (model selection)
  - individual meetings

Study design

- Generalizing
  - How do I want this to generalize?
  - What population to generalize to?
  - What is the scope of inference?
- Generalization is determined by the design not the analysis
- Study design is best done before data collection

Study design

- Sampling design
  - observational
  - estimation
- Experimental design
  - manipulative
  - causal inference

To find out what happens when you change something,
it is necessary to change it

Box, Hunter, and Hunter (1978)

Design fundamentals

- Identify a population of inference: scope
- Identify sample or experimental unit
- Confounding — main issue
- Replication
- Randomization
- Control

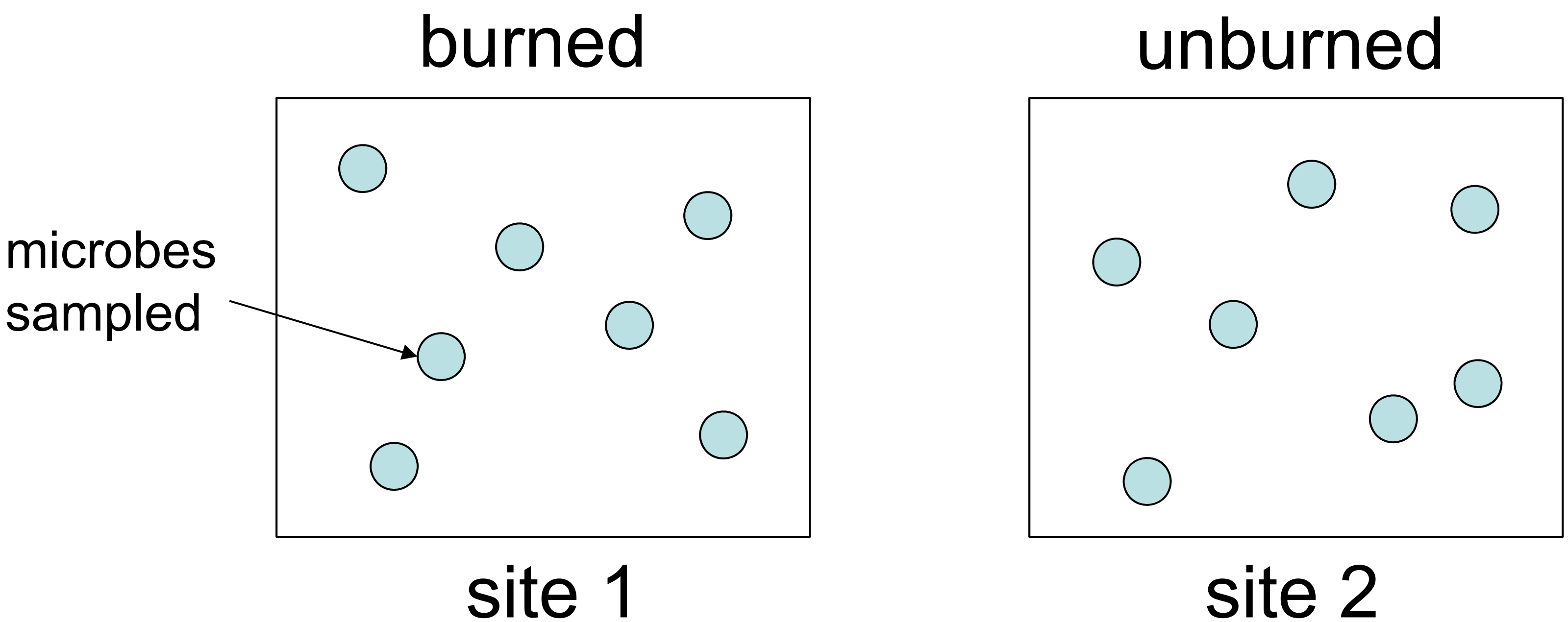
main remedies

Replication

- 1 replicate = confounded with unit
- How much replication?
  - depends on effect size and variance
  - rule of thumb: < 20 d.f. is treacherous
- Degrees of freedom (d.f.)

  = n – number of parameters

Confounding examples



burn and site are confounded

Confounding examples

Process all of treatment 1

before lunch

Process all of treatment 2

after lunch

What’s wrong?

Confounding examples

Process all of treatment 1

before lunch

time 1
environment 1?

Process all of treatment 2

after lunch

time 2
environment 2?

treatment and time are confounded

Confounding examples

Put all of treatment 1

left side of bench

Put all of treatment 2

right side of bench

What's wrong?

Confounding examples

Put all of
treatment 1

left side of
bench

space 1
environment 1?

Put all of
treatment 2

right side of
bench

space 2
environment 2?

treatment and space are confounded

Pseudoreplication

- Replicates are grouped
- Grouping = confounding

Randomization

- Fixes confounding by shuffling potential confounders
- Random sampling: allows inference to population (scope)
- Random assignment: allows causal inference about a treatment

Simple random sample

- Number each individual in the population
- Use a random number generator to draw individuals at random
- Unbiased sample
- Ensures unbiased estimate

Stratified random sample

- Divide the statistical population into sub-populations
- Random sample within sub-populations
- Examples
  - male/female
  - different habitat types
  - species 1 / species 2

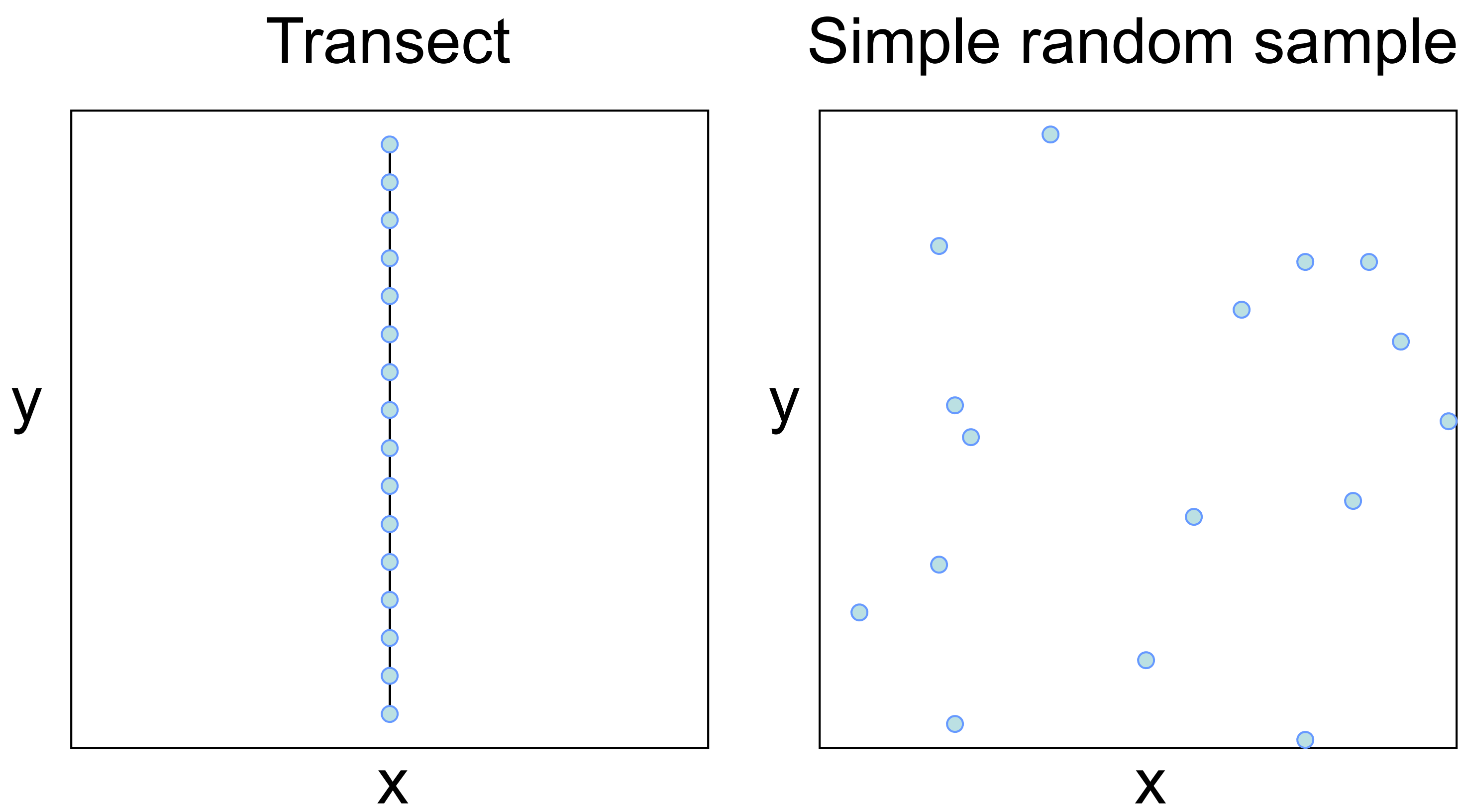
Nested random sample

- Example
  - trees / branches / leaves
- Randomly sample trees within forest
- Randomly sample branches within trees
- Randomly sample leaves within branches
- Scope: leaves within a forest

Systematic sampling

- Opposite of random
- Examples
  - transects with equal spacing of samples
  - spatial grid
  - every Thursday
- Bias
- Autocorrelation
- Scope

Example:
spatial
sample

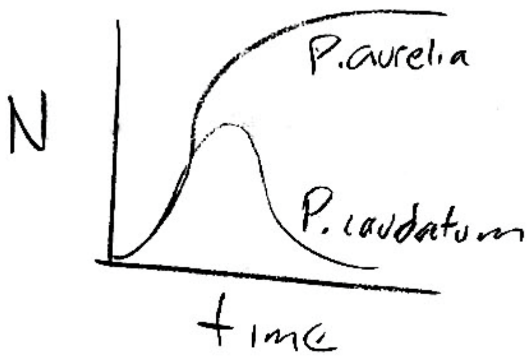


Bias:	one x; gradient on y?	none
Autocorrelation:	strong, systematic	weak, diffuse
Scope:	this transect	population

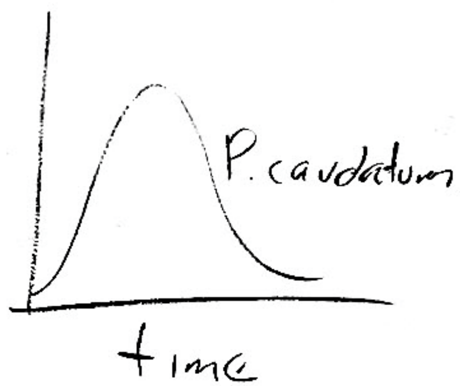
Controls

Systematically controlling for potential confounders

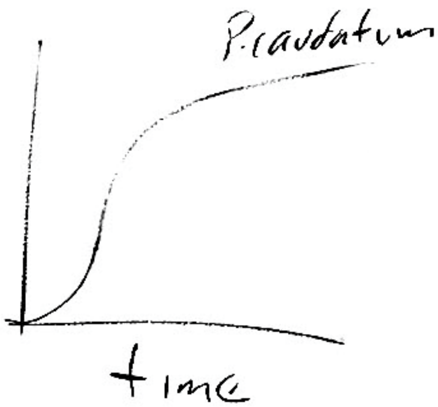
Classic example: Does *Paramecium aurelia* exclude *P. caudatum*?



P. aurelia present
actual outcome



P. aurelia absent
possible outcome 1

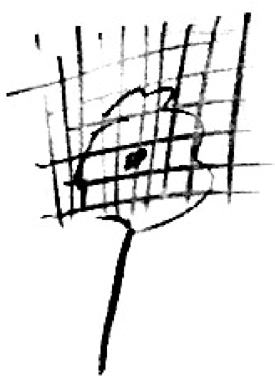


P. aurelia absent
possible outcome 2

Presence of *P. aurelia* is confounded with time.
We need a control (absence of *P. aurelia*) to distinguish the two possible outcomes through time.

Controls

- Cage effects
  - examples: pollinator exclusion, herbivore exclusion
  - exclusion is confounded with changes to the environment caused by the cage



mesh bag

control 1: no bag

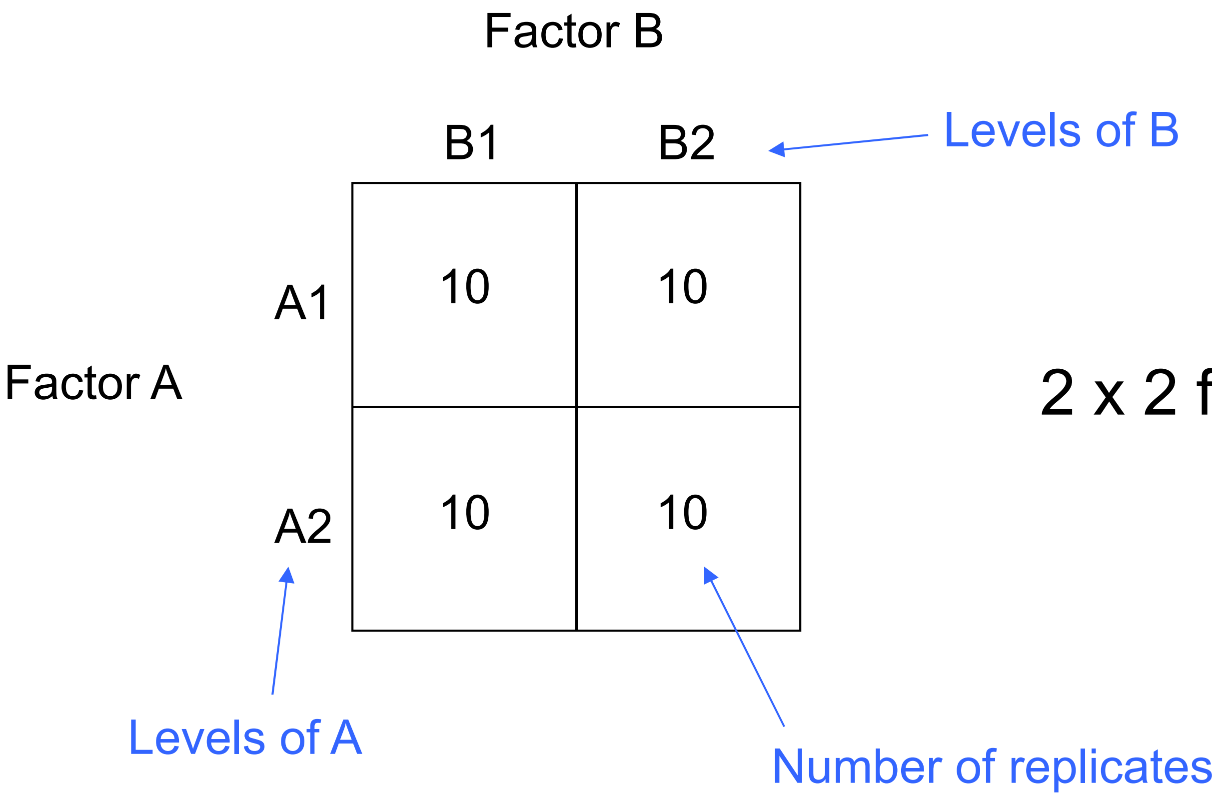
control 2: bag with holes

e.g. exclude pollinators from flowers. Control 2 attempts to measure confounding effect of environment while allowing pollinators. Very difficult issue to control.

Controls

- Handling effects
  - confounder: handling changes behavior
- Example: hormone treatment
  - catching and injecting an animal changes it's behavior
  - control: catch and sham inject

Factorial design



2 x 2 factorial

Advantage: allows us to estimate interactions

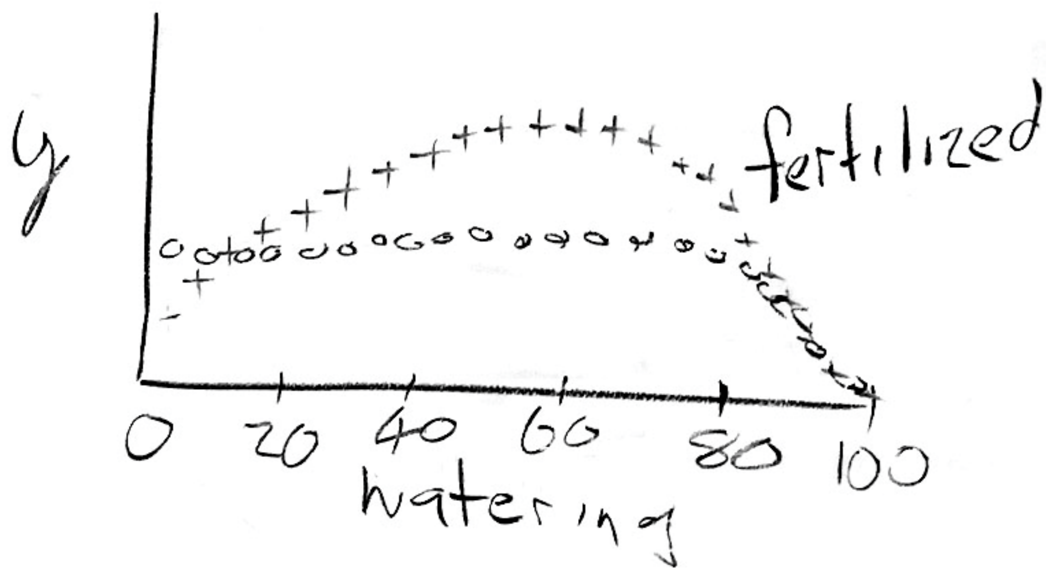
Factorial design

- Many possibilities
  - 2 x 2 x 2 = cube
  - 2 x 2 x 2 x 2
  - 3 x 2
  - 5 x 4
  - ...

Factorial versus response surface design

Fertilize	Water 20	40	60	80	100
+	5	5	5	5	5
-	5	5	5	5	5

50 experimental units
no interaction
# parameters = 7
df = 50 - 7 = 43
with interaction
# parameters = 11
df = 50 - 11 = 39

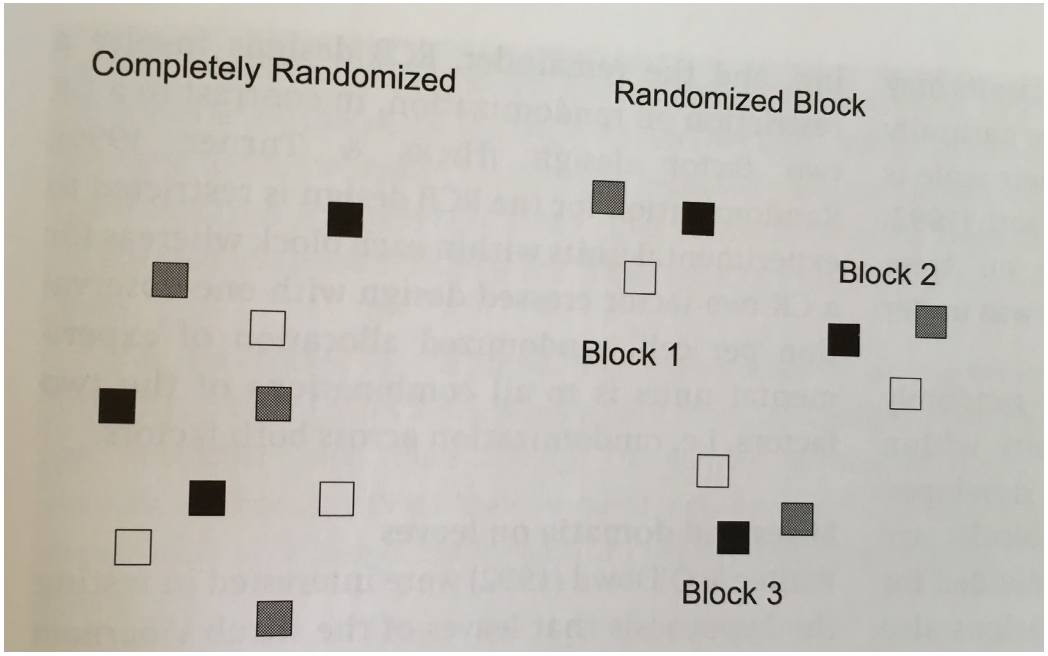


50 experimental units
3 parameters per curve
df = 50 - 7 = 43
5 parameters per curve
df = 50 - 11 = 39

Advantage: can get much better nonlinear resolution for same replication

Multilevel designs

- Randomized block



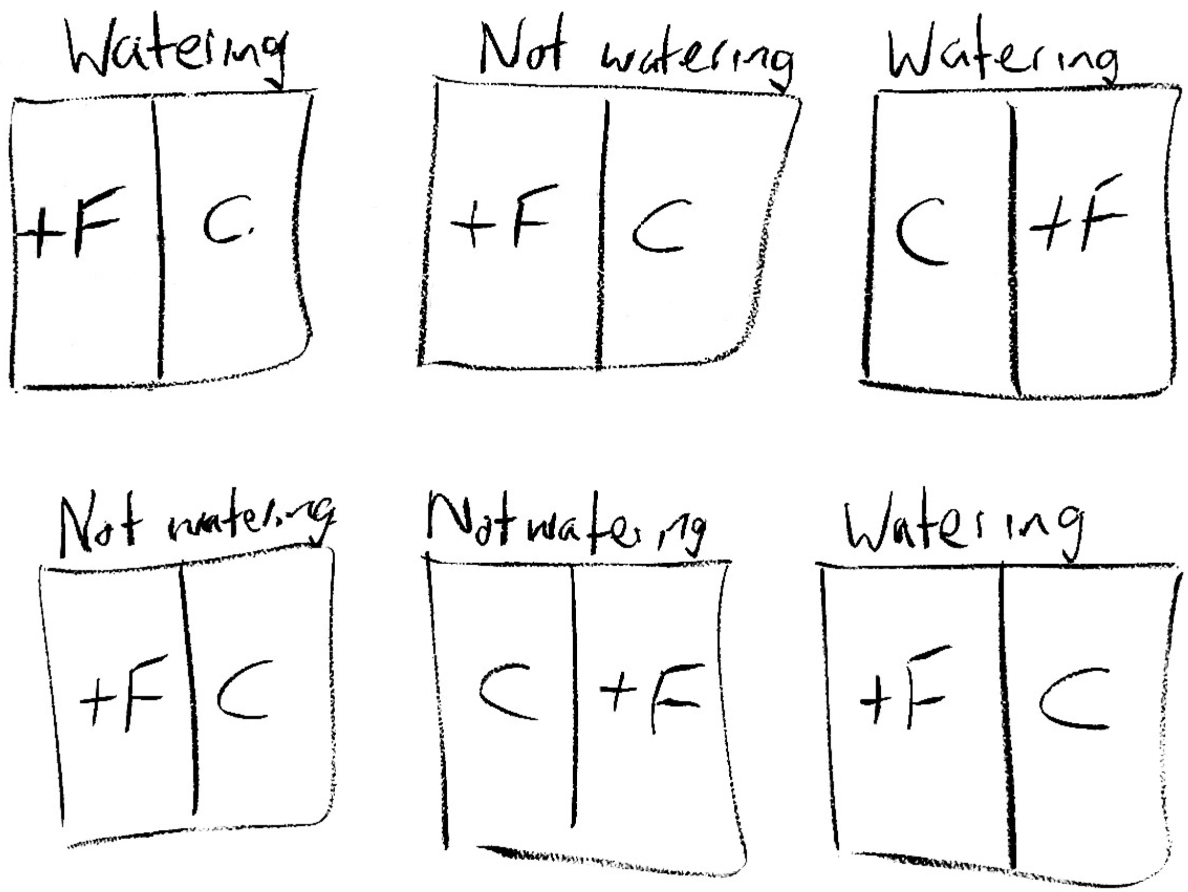
Example spatial design with three treatments (box colors)

Contrasted with completely randomized design

Pros: account for large scale variation
Cons: penalty for more complex model (grouping variable)
Whether it helps depends on this tradeoff

Multilevel designs

- Split plot



Plots are split into sub-plots.

Watering treatment is at large scale (plot), fertilizer treatment is at small scale (sub-plot).

Pro: watering simpler
Con: replication of large scale factor is reduced (3)
Con: penalty for model complexity (need a grouping variable)

Space and time

- Repeated measures
- When are space or time grouping variables (random effects)?

Boulder county trails

Example from ecology undergrad field class
Effect of distance from hiking trails

How would you design this?

Think about this in terms of
- scope of inference
- amount of replication
- logistics
- grouping vs no grouping
- autocorrelation
- pseudoreplication