ENV 710: Lecture 8

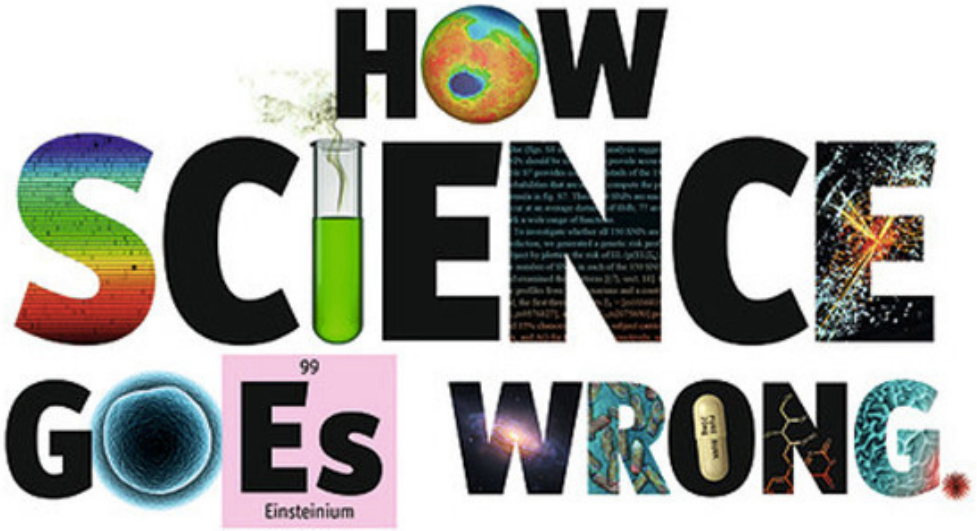
experimental design

Duke | NICHOLAS SCHOOL OF THE ENVIRONMENT


COMMON SENSE

Crisis of Irreproducibility

... many supposedly scientific results cannot be reproduced, because of improper use of statistics, arbitrary research techniques, lack of accountability, political groupthink, and a scientific culture biased toward producing positive results...

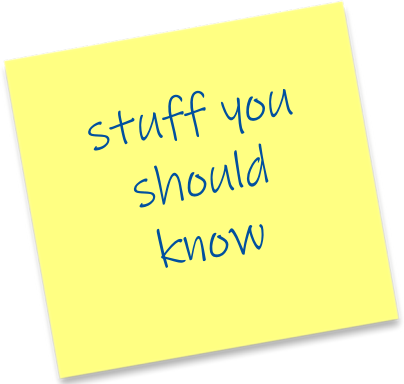


experimental design

sampling and study design

learning goals

- what is the scientific process?
- what are the important components of study design?
  - control replication, randomization, blocking
  - terms: treatment, control, covariates, factors, etc…
- what are the classes of traditional study designs?
  - ANOVA, regression, etc…



the scientific process

1) I want to study elephants
2) I have an awesome new method
3) spend 3 months somewhere
   exotic collecting data
4) think of a question
5) analyze your data…

… realize you haven't collected the right data

the fun scientific process

1) I want to study elephants
2) I have an awesome new method
3) spend 3 months somewhere
   exotic collecting data
4) think of a question
5) analyze your data…

… realize you haven't collected the right data

the question comes first

if you don't think deeply about your question, you will likely end up with flawed and unusable data

https://www.proprofs.com/quiz-school/story.php?title=science-district-assessment-1-20152016

scientific process

- specify objectives of the study — the question!
- design the study — use principles of study design
- study execution — the fun bit
- statistical analysis — even more fun!
- interpretation of results and conclusions
- next study - the cycle continues…

RINSE. WASH. REPEAT.

sampling

- goal of statistical inference is to draw conclusions about a population from data collected on selected individuals

statistical inference: sample ⟶ **population**

- want to say something about a population - the entire group of individuals that we want information about.
- to get at this we take a sample - a part of the population that we examine to gather information

parameters vs. statistics

- a parameter is a number that describes the population; it is a fixed number, but in practice we do not know the number
- a statistic is a number that describes a sample; its value is known when we have taken a sample, but it can change from sample to sample

sampling design

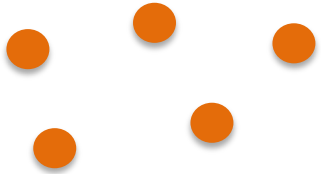
- sampling design, the method chosen to select the sample from the overall population
- a sampling method is biased if it systematically favors certain outcomes
- to minimize the possibility of bias use chance to select samples, so that all individuals have an equal chance to be in the sample

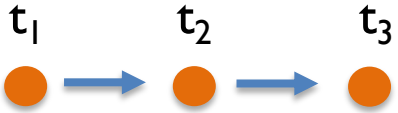
- probability sampling - each member of the population has a known chance (greater than zero) of being selected
- simple random sample – n individuals from the population chosen so that every set of n individuals has an equal chance of selection
- stratified random sample - divide the population into groups of similar individuals, called strata, then choose a separate simple random sample in each stratum and combine to form the full sample

experiments

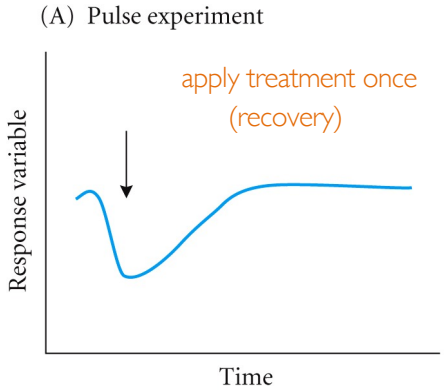
natural vs.
manipulative experiments

snapshot vs.
trajectory experiment

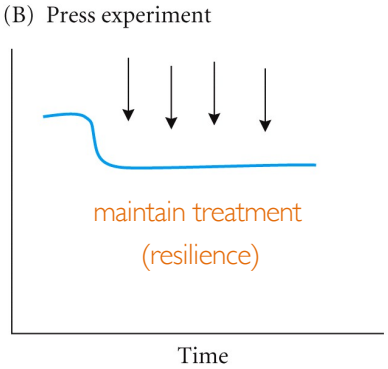




pulse vs.
press experiments



A PRIMER OF ECOLOGICAL STATISTICS 2e, Figure 6.4



experiments

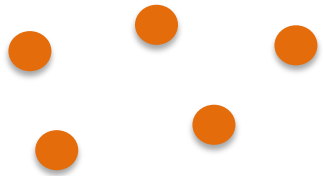
natural vs.
manipulative experiments

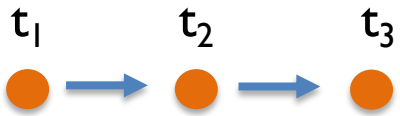
- experimental studies are manipulative
- observational studies are not truly experimental because there is no manipulation, rather take advantage of natural variation

experiments

snapshot vs.
trajectory experiment

- snapshot - replicated in space
- trajectory - replicated in time (monitoring)
- consider spatial and temporal dependence

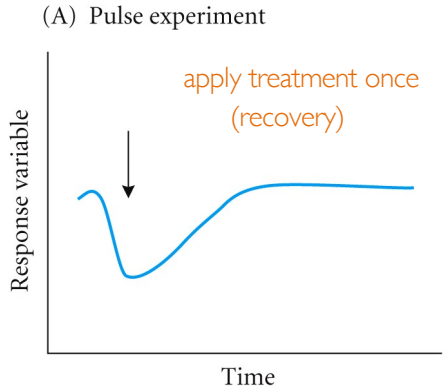




experiments

- pulse, experimental treatments are applied once, and the replicate is allowed to recover
- press, strength of the manipulation remains constant
- use of press and pulse experiments depends on what you are interested in studying

pulse vs.
press experiments



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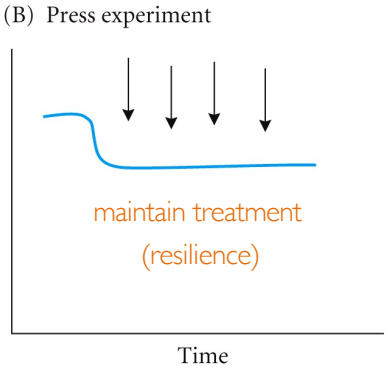


example

effects of fire

What are the effects of different fire cycles on bird diversity in a western US temperate forest?

natural vs. manipulative experiments

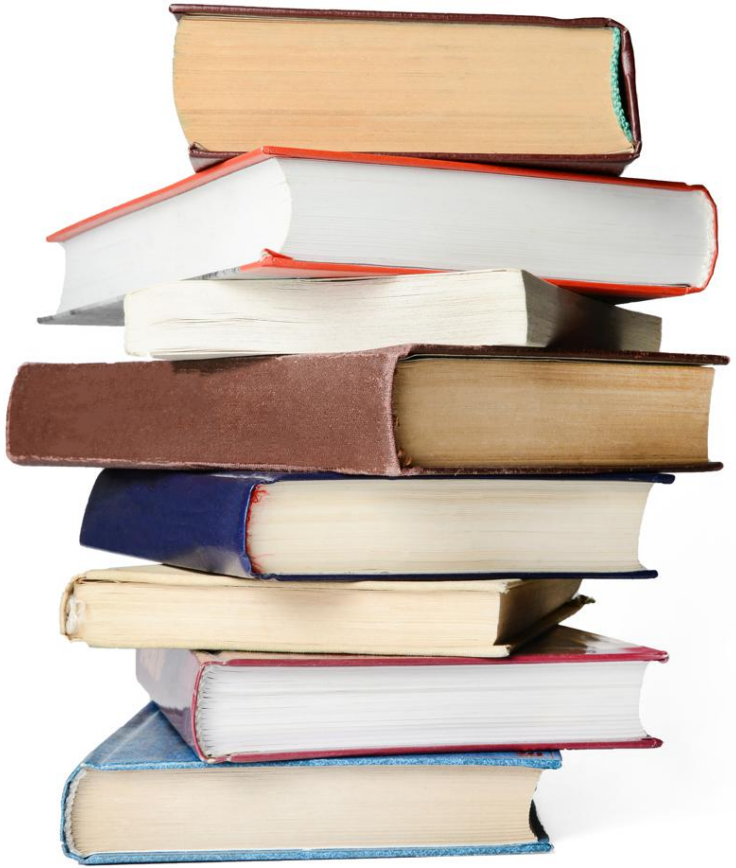
snapshot vs. trajectory experiments

pulse vs. press experiments

how would you set up this experiment?
pros and cons of different types of experiments?

principles of study design

- control
- randomization
- replication
- blocking

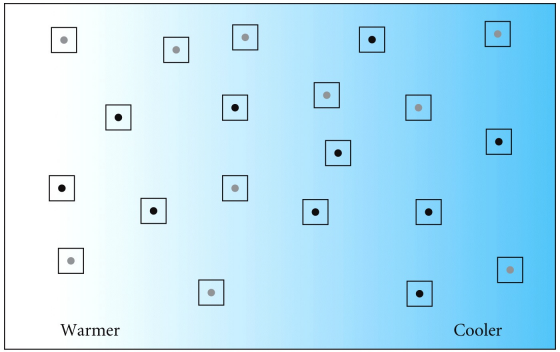


control – replicates without the treatment

- serves as a baseline for comparison with treatment groups
- controls should receive same manipulation as treatments

randomization - random assignment of treatments to avoid unintended biases that could affect the treatments

- every possible allotment of treatments should have the same probability
- randomization removes bias and sources of uncontrollable extraneous variation



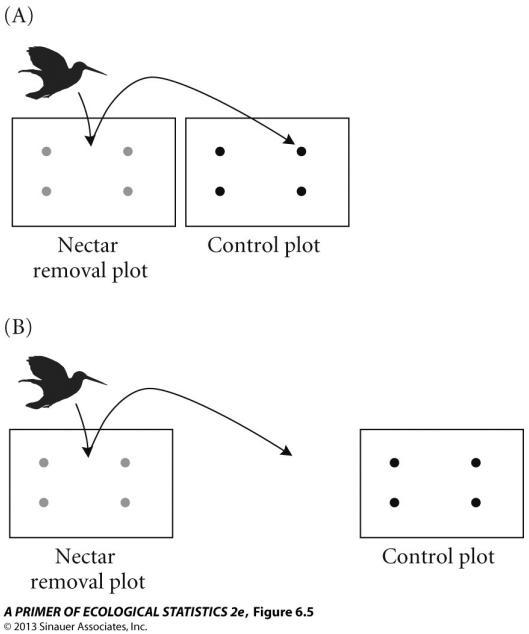
A PRIMER OF ECOLOGICAL STATISTICS 2e, Figure 6.7

"There's a flaw in your experimental design. All the mice are scorpios."

replication is repetition of the set of all the treatment combinations to be compared in an experiment

- replicates are assumed to be independent
- replicate experimental units of each treatment
- replication avoids confounding effects

- provides a measurement of variability within a treatment
- replication increases precision through increased sample size



A PRIMER OF ECOLOGICAL STATISTICS 2e, Figure 6.5

pseudoreplication

"the use of inferential statistics to test for treatment effects with data from experiments where either treatments are not replicated (though samples may be) or replicates are not statistically independent." -- Hurlbert

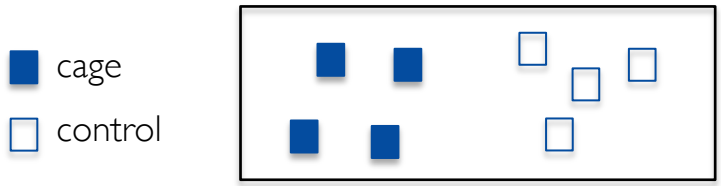
- underestimates variability of data, resulting in CI's that are too small and an inflated Type I error

Solutions?

(a) avoid it

(b) minimize the lack of independence in the pseudo-replicates

(c) be honest about the limitations of the study



example

CO_2 chamber

- A researcher is studying the effect of different concentrations of CO_2 in the air on plant growth.
- She grows the plants in a growth chamber so that CO_2 concentration can be controlled. There are two growth chambers, each will hold five plants.
- What is the experimental unit (or replicate)?

example

CO_2 chamber

- The growth chambers are the experimental units
- The five plants in each chamber share whatever conditions are in that chamber besides the CO_2 concentration
- The plants in a chamber are not independent replicates because treatments are applied to the growth chambers, not to the plant independently

blocking – is the arranging of experimental units in groups (blocks) that are similar to one another

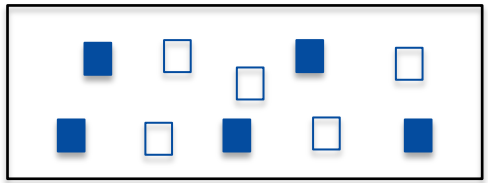
- create groups of similar characteristics to reduce variation within groups
- controls the effect of nuisance variables that aren't of interest
- increases precision without increasing replicates

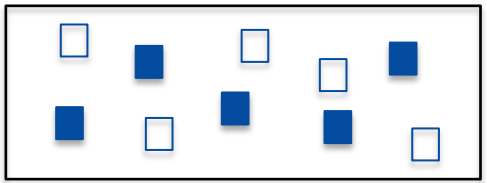
high elevation

cage

control

low elevation

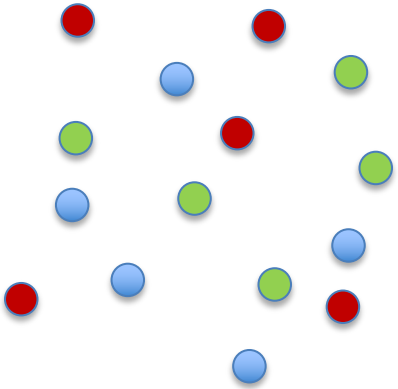


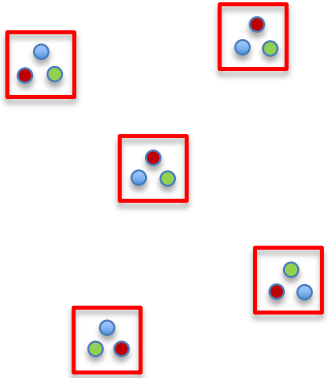


example

effects of fire

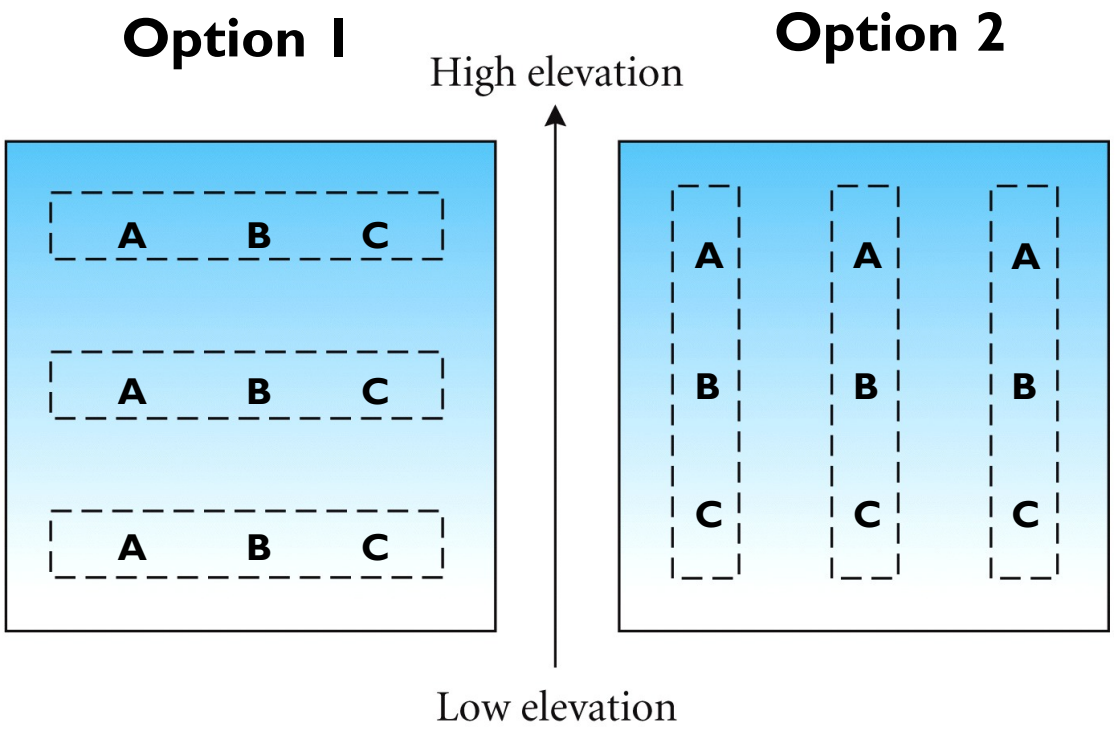
- completely random design – 3 treatments applied to 15 experimental units (5 reps per treatment)
- randomized block design – 3 treatments allocated randomly to the 15 experimental units within each of 5 blocks, each constructed to be as homogenous as possible





example

effects of fire



A PRIMER OF ECOLOGICAL STATISTICS 2e, Figure 7.7

experimental design

scale, covariates, effort

types of variables

- categorical variables vs. continuous variables

  categorical variables are classified in 2 or more categories: (pass, fail), (producer, herbivore, carnivore)

  continuous - measured on continuous numerical scale

- dependent vs. independent variables

  dependent = response variable

  independent = predictor variable, hypothesized to be responsible for variation in the response variable

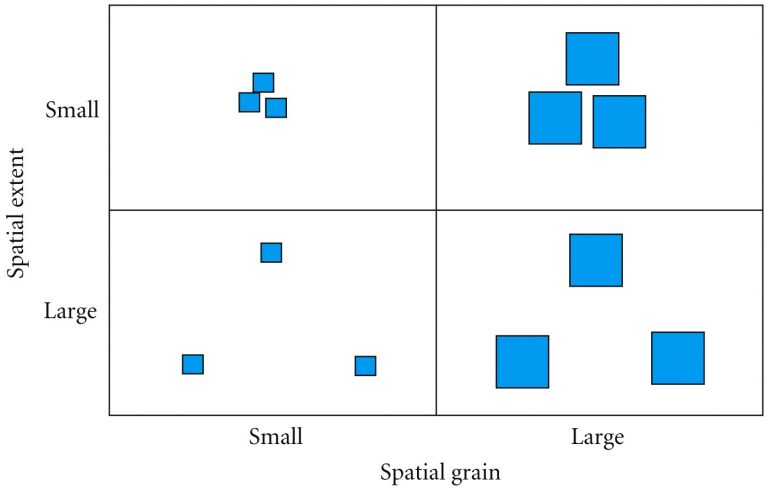
covariates

covariates are variables that potentially affect the response variable, but are not controlled or manipulated

what are potential covariates for the fire study?

scale of study

- treatments must be at appropriate scale
- grain is the size of the smallest unit of study (i.e., size of an individual replicate)
- extent is total area encompassed by all the sampling units in the study



A PRIMER OF ECOLOGICAL STATISTICS 2e, Figure 6.9

survey effort

- same number of units in each treatment
- equal survey effort *a.k.a.* balanced design optimizes precision
- helps (but does not guarantee) statistical independence
- there may be legitimate reasons for unbalanced designs, e.g. camera trap failure

experimental design

classic designs

example

barnacles

A researcher wants to understand the effect of substrate type on barnacle recruitment a rocky intertidal zones.

Places three substrates (slate, granite, cement) into the rocks and leaves them for two weeks.

1. What is the treatment?
2. How many levels of treatment?
3. What is the response variable?
4. How many replicates?

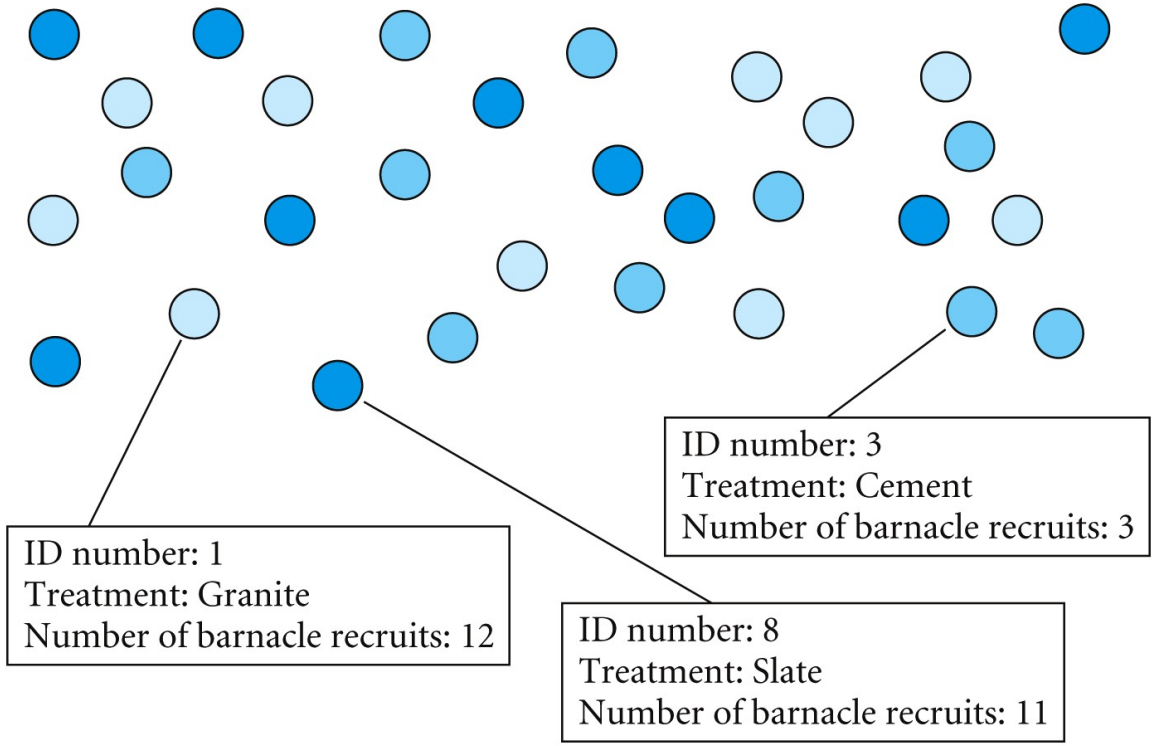
Substrate	ID	No. of barnacles
Granite	1	12
Slate	1	10
Cement	1	3
Granite	2	14
Slate	2	10
Cement	2	8
…	…	…
Cement	30	8

one-way layout

simple and powerful

maybe too simple!

can't cope explicitly with heterogeneity



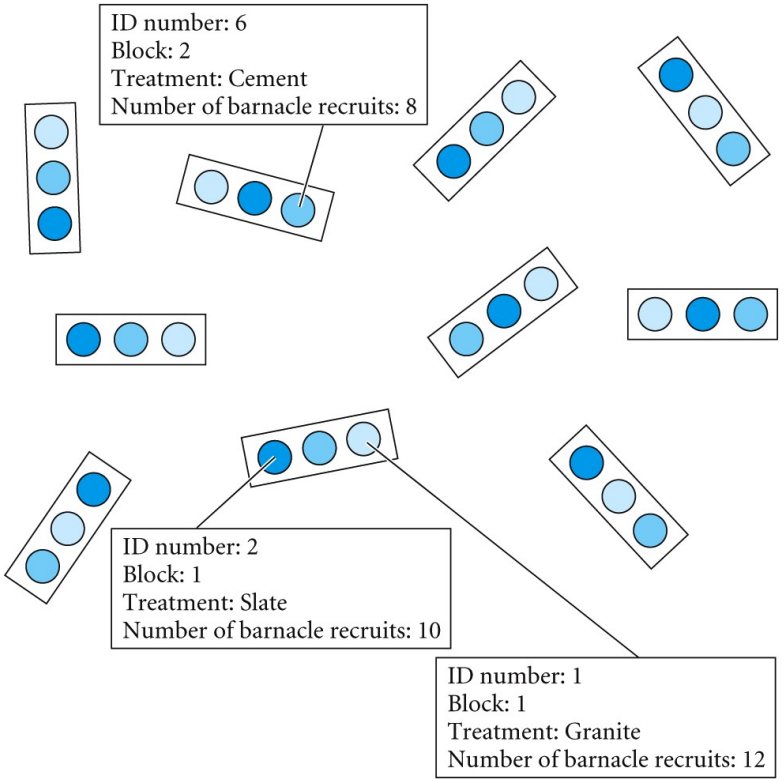
***A PRIMER OF ECOLOGICAL STATISTICS 2e*, Figure 7.5 (Part 1)**

block design

- place units into homogenous subgroups
- treatments randomly assigned for each subgroup

control for confounding factors

more powerful than the simple design



***A PRIMER OF ECOLOGICAL STATISTICS 2e*, Figure 7.6 (Part 1)**

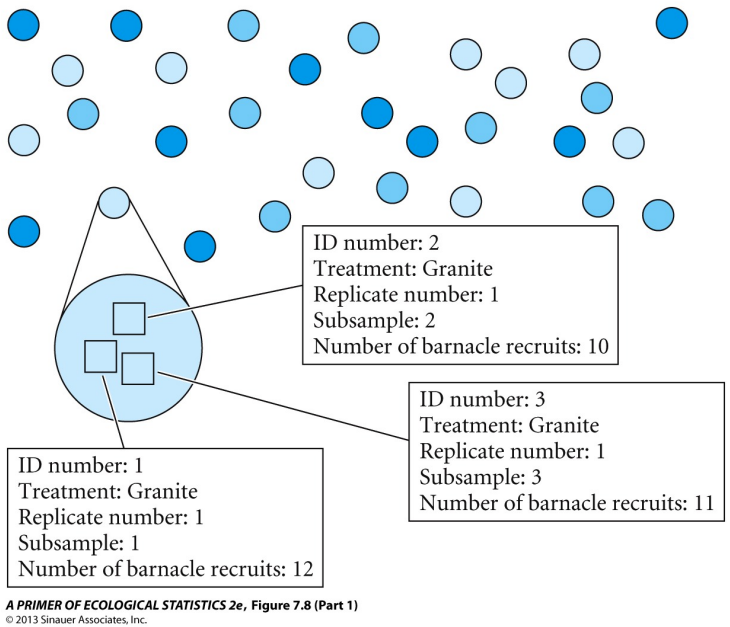
if block effect is weak, less useful

careful with independence

nested design

nested designs involve subsampling within each replicate

- increases precision of estimate for each replicate
- can test for variation among treatments and variation among the replicates within a treatment
- can be extended to hierarchical sampling design



A PRIMER OF ECOLOGICAL STATISTICS 2e, Figure 7.8 (Part 1)

increases precision
added level of inference

analyse data carefully as it is not independent
doesn't increase replicates

more than just substrate?

- include predation in the experiment too

4 additional treatments

Control

Whelk exclusion

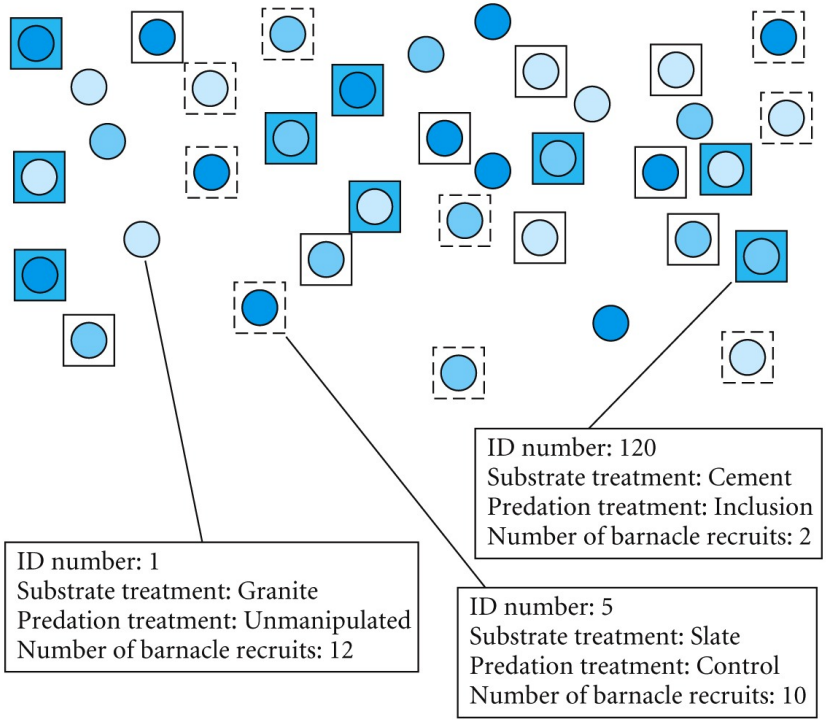
Whelk inclusion

Unmanipulated

factorial design

2 or more factors are tested simultaneously in one experiment

- treatments must be fully crossed: every level of the 1st factor much be represented with every level of the 2nd factor
- tease apart main effects and interactions among two factors



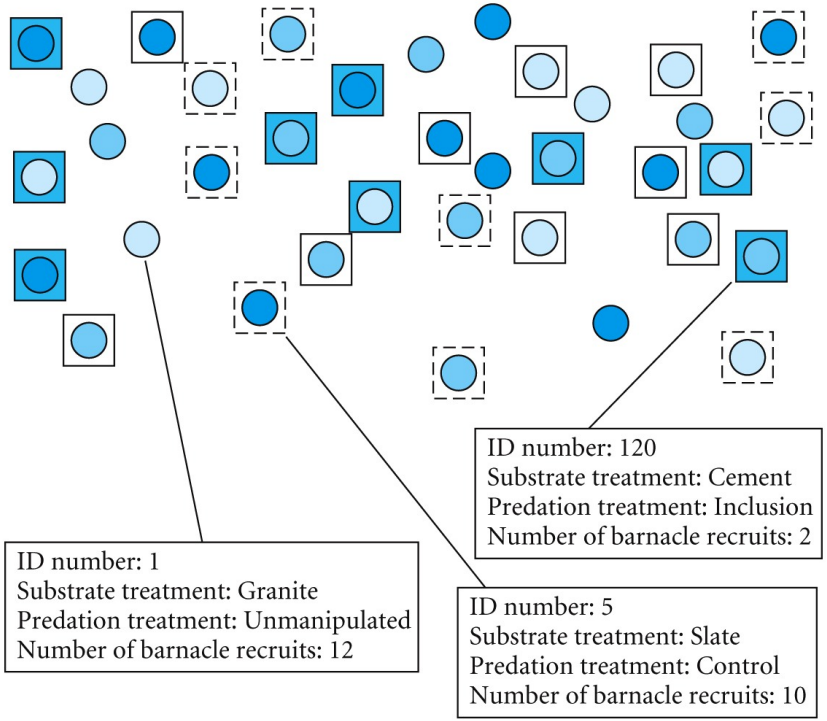
***A PRIMER OF ECOLOGICAL STATISTICS 2e*, Figure 7.10 (Part 1)**

factorial design

number of experimental units?

3 substrates x 4 caging treatments x 10 replicates = 120 exp. units

a lot of work, maybe expensive, and sometimes all treatments are not 'natural'

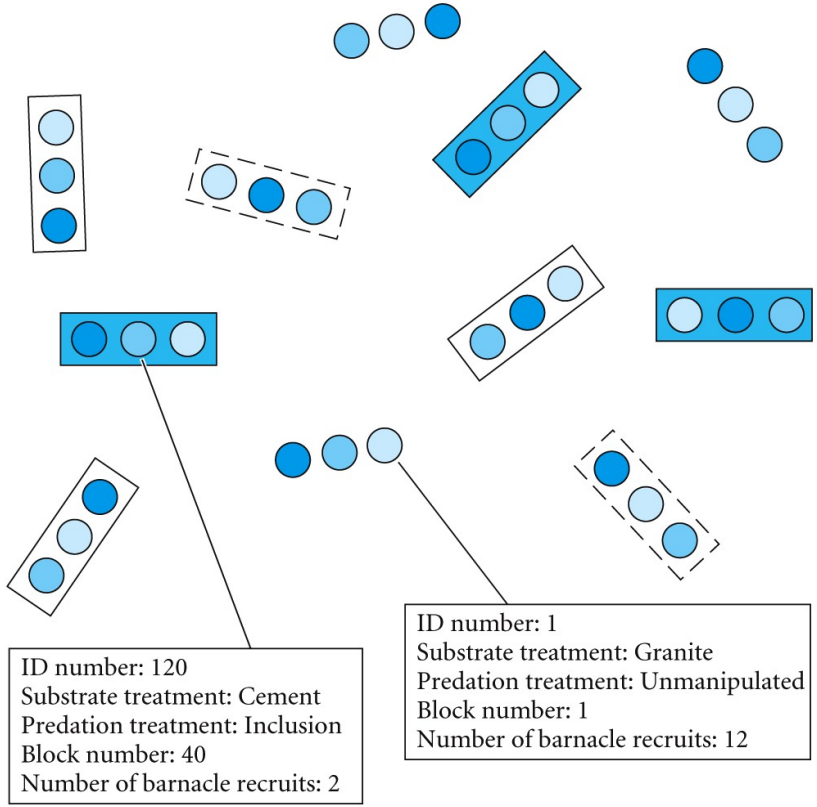


***A PRIMER OF ECOLOGICAL STATISTICS 2e*, Figure 7.10 (Part 1)**

split plot design

single plot is divided into subplots, each of which receives a different treatment

- can tease apart main effects and interactions among two factors
- second treatment is applied over all the replicates within a single block
- chief advantage is the efficient use of blocks for the application of two treatments



***A PRIMER OF ECOLOGICAL STATISTICS 2e*, Figure 7.12 (Part 1)**

Post your questions to be answered during lecture