

# Lecture 10

## **Quasi Experiments- Before-After-Control-Impact Designs**

### Examples

**Quasi Experiments- Other Weaker Designs are contrasted to the BACI**

# Guest Lectures Coming Up

Jim Gilliam will come on Thursday February 21, 2008. Carefully read his paper in advance. Posted on the website

Ted Simons will come on Thursday February 28, 2008

# BACI: BEFORE, AFTER, CONTROL, IMPACT DESIGNS

- Need to measure response on control and impacted sites both before and after the impact.
- BACI very very useful design when lack of randomization is the only problem.
- BACI assumes if no impact took place then the control and impact sites track each other (i.e. one would have parallel lines.)
- Planned Impact like building a power plant on a lake where it is possible to obtain information on similar lakes without power plants.(i.e. control lakes are replicated)
- Sometimes just have one control and one impacted lake say and have “**replicate**” sites within each. Restricted inference just to the effect on that one lake of the power plant. This is pseudo replication but it may be the best one can do in practice.

# **Replicated and Unreplicated BACI Examples**

## **Unreplicated BACI Studies- Two Examples (Already Considered)**

- Bence et al (1996).Ch 8 in Detecting Ecological Impacts: Concepts and Applications in Coastal Habitats .Eds Schmidt and Osenberg.Academic Press.
- Likens et al. (1970) Ecological Monograph, Likens et al. (1978) Science Volume 199 p 492- 496.Classic Hubbard Brook, New Hampshire Study on Deforestation.

## **Replicated BACI Studies- Two Examples (Today)**

- Downs et al.2002.Monitoring Ecological Impacts : Concepts and practice in flowing waters. Cambridge University Press. p 234-248.
- Read and Andersen (2000). J of Arid Environments 45, 231-251. (Just mentioned as it is not really totally replicated)

# BACI DESIGNS ANALYSIS METHODS

## Types of Analyses

### No Replicates

Time Plots, Possibly (but rarely) time series analysis

### Replicates

One time point- T Tests (Rank Tests).

Multiple time points- Repeated Measures ANOVA. I will only cover briefly.

# BACI DESIGNS: ANALYSIS FOR ONE TIME POINT

## Replicates are Possible

One time point or a summary measure over time (often the mean).

## Standard Designs

**Unpaired Sites** - Two sample T test or Two Sample Rank test

**Paired Sites**- Paired T test or Signed Rank test

**Note** -*Sometimes only replicate control sites possible, Sometimes pairing sites altho desirable is not possible.*

# Consider the Structure of the data

- We will use the paired control and impacted plot design where before and after data is collected
- We will look at how the difference between the impact plot after-before vs the control plots after-before
- By combining these we can eliminate any time effect just leaving the impact effect.

# Paired Control and Impact Plots ( $i = 1, 2, \dots, n$ )

## Control Plot Component

$(X_{CAi} - X_{CBi})$  is difference for control site  $i$  after - before

Measures Time Effect or Change Only

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# Paired Control and Impact Plots ( $i = 1, 2, \dots, n$ )

## Impacted Plot Component

$(X_{IAi} - X_{IBi})$  is difference for impacted site  $i$  after – before.

Measures (Impact Effect + Time Effect)

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## Paired Control and Impact Plots ( $i = 1, 2, \dots, n$ )

Both Components Shown

$(X_{IAi} - X_{IBi})$  is difference for impacted site  $i$  after – before.

Measures (Impact Effect + Time Effect)

$(X_{CAi} - X_{CBi})$  is difference for control site  $i$  after - before

Measures Time Effect Only

## Paired Control and Impact Plots ( $i = 1, 2, \dots, n$ )

$(X_{IAi} - X_{IBi})$  is difference for impacted site  $i$  after – before.

Measures (Impact Effect + Time Effect)

$(X_{CAi} - X_{CBi})$  is difference for control site  $i$  after - before

Measures Time Effect Only

$$D_i = (X_{IAi} - X_{IBi}) - (X_{CAi} - X_{CBi})$$

is an estimate of the Impact Effect on Site  $i$ . The Time Effect has been eliminated -

**Crucial Assumption : Parallel Response for Control and Impact Sites except for impact effect.**

# BACI DESIGNS: SIMPLE ANALYSIS METHOD WITH ONE MEASURE AND NORMALITY ASSUMED

Paired Control Impact Plots

$$D_i = (X_{IAi} - X_{IBi}) - (X_{CAi} - X_{CBi})$$

$i = 1, \dots, n$  (paired sites)

$H_0 \mu_D = 0$  No Impact

$H_1 \mu_D \neq 0$  Impact

Carry out paired t test

$$\text{Statistic } T = \frac{\bar{D}}{\sqrt{\frac{s_D^2}{n}}}, \text{ df} = (n - 1)$$

Calculate p value etc

# First Pair

$$D_1 = (X_{IA1} - X_{IB1}) - (X_{CA1} - X_{CB1})$$

$$D_1 = (7.5 - 6.1) - (6.4 - 6.2)$$

$$D_1 = (+1.4) - (+0.2)$$

$$D_1 = 1.2$$

See Spreadsheet

Compute all Differences and then carry out the  
T test.

# BACI DESIGNS: SIMPLE ANALYSIS METHOD WITH ONE MEASURE AND NON NORMALITY ASSUMED

Paired Control Impact Plots

$$D_i = (X_{IAi} - X_{IBi}) - (X_{CAi} - X_{CBi})$$

$i = 1, \dots, n$  (paired sites)

$H_0 \mu_D = 0$  No Impact

$H_1 \mu_D \neq 0$  Impact

Compute Signed-Rank Statistic

Rank the differences ignoring the signs

Count up the ranks of the differences that are +.

Find p value of test.

# BACI DESIGNS: SIMPLE ANALYSIS METHOD WITH ONE MEASURE AND NON NORMALITY ASSUMED

Suppose there were 6 differences :

-1,+3,+4,-3,+2,+1

Absolute Ordered Differences

1,1,2,3,3,4,

*Ranks*

1.5;1.5; 3; 4.5; 4.5; 6.

*Sum + Ranks*

$$T^+ = 1.5 + 3 + 4.5 + 6 = 15^{ns}$$

Note :  $T^+ = 21$  is the 5% point (Table)

# Shorebird Disturbance Study

- Lets discuss this briefly

# BACI: DESIGNS ANALYSIS FOR MULTIPLE TIME POINTS

- Repeated Measures Analysis of Variance Table is very useful
- F test on the interaction of (impact vs control)\*(before vs after) is the key. We will illustrate more concretely for the liming example which follows.

# BACI:DESIGNS LIMING EXAMPLE

- Rundle et al. 1995.Freshwater Biology 34,165-175
- Reported in Downs et al.2002.Monitoring Ecological Impacts : Concepts and practice in flowing waters. Cambridge University Press.p 234-248.
- River Tywi in Wales.Remediation study on streams affected by acid rain.1984-1994.
- 3 Control and 3 Limed sites with 3 yrs before and 3 years after. Thus in this example we do have replication. Also somewhat unusual as in this case the treats were or could have been randomized when they usually cannot be randomized.
- Measures are no's of macro invertebrates of acid sensitive taxa.

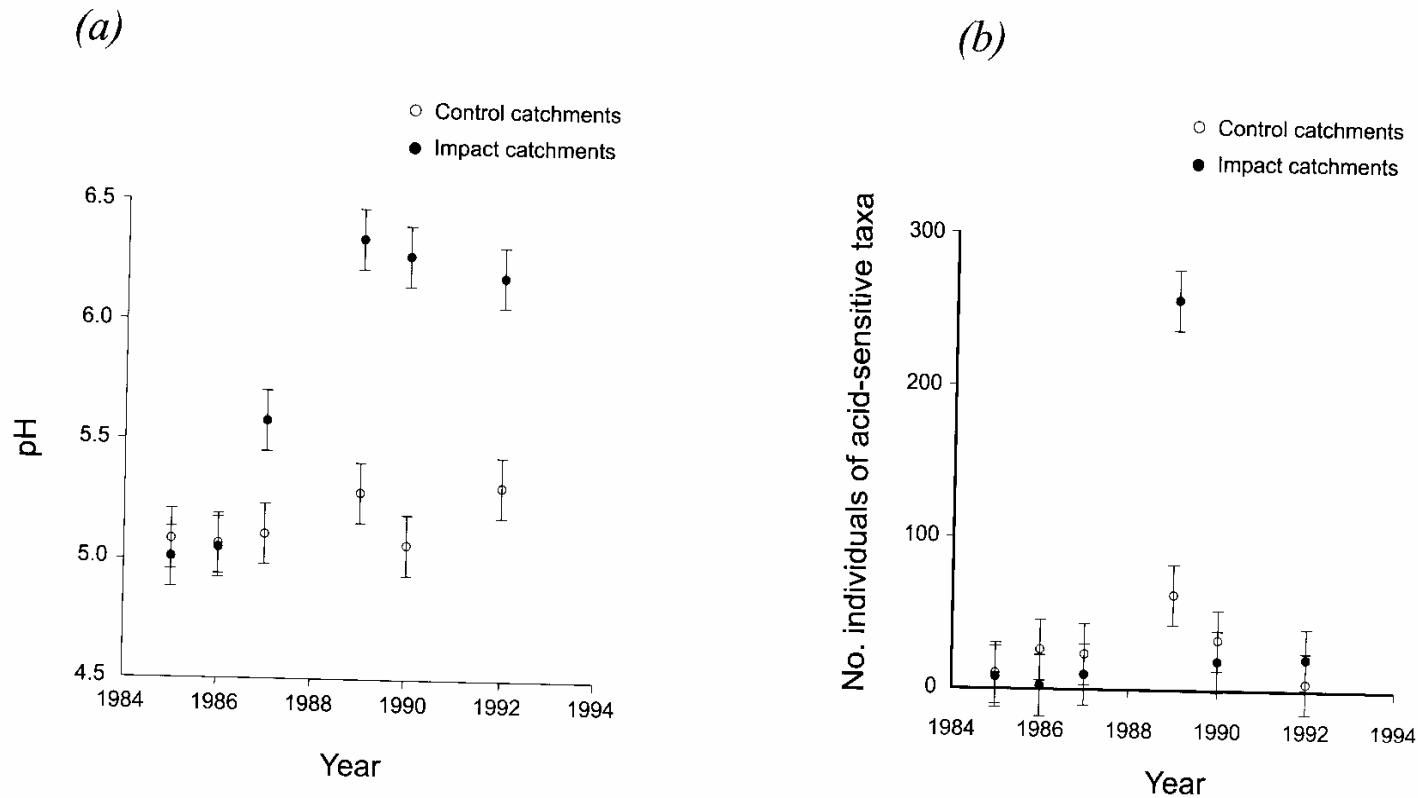
# LIMING EXAMPLE: SITE CHARACTERISTICS

Table 8.9. Characteristics of control and impact locations in the Welsh liming study, including relevant measures of water chemistry

Code	Locations	Catchment area (ha)	Slope	Mean pH	CaCO <sub>3</sub> (mg L <sup>-1</sup> )	Filterable Al (mg L <sup>-1</sup> )
<i>Control locations</i>						
C1	Moorland	15	0.124	5.2	3.9	0.10
C4	Moorland	71	0.063	5.3	4.5	0.12
L1	Coniferous afforestation (~ 30 years old)	264	0.096	4.8	5.3	0.36
<i>Impact locations</i>						
C2	Moorland	77	0.072	5.0	3.9	0.16
C5	Moorland	33	0.085	5.2	4.2	0.15
L4	Coniferous afforestation (~ 30 years old)	32	0.113	5.0	7.1	0.17

Source: Rutt et al. (1989).

# LIMING EXPERIMENT: MEANS and STANDARD ERRORS



**Fig. 8.8** Results of the liming experiment in the River Tywi catchment. Liming occurred in late 1987 and early 1988. (a) The average, annual mean pH at control and impact locations in different years. (b) The mean total number of individuals of acid-sensitive taxa present in control and impact locations in different years. In each graph, the error bars are standard errors derived from the appropriate MS term in the analysis.

# **LIMING EXAMPLE: FORMAL STATISTICAL ANALYSIS.**

## **REPEATED MEASURES ANOVA.**

**Similar but more complex than the repeated measures ANOVA for simple experiments.**

**Look back to earlier lectures**

# LIMING EXAMPLE: REPEATED MEASURES ANOVA

## Two parts to the ANOVA

two error terms.

Compound Symmetry assumption that the correlation between time pts is constant irrespective of how far apart they are.

**Whole Plots** -6 locations (3 Control and 3 Limed in yr 4)

Therefore 6 whole plot units (5 df)

There are no important tests here

**Split Plot (Repeated Measure )**- 6 yrs (3 before and 3 after)

Therefore 36 total split plot units (35 df)

The impt tests are in this part of the table.

Table 8.11. Repeated measures analysis of variance of the total numbers of individuals of all 18 acid-sensitive taxa within samples

Source	SS	df	MS	F-ratio	P
<i>Among locations</i>					
Impact vs. Control	6110.03	1	6110.03	2.095	0.221
Locations <sub>within I vs. C</sub>	11668.44	4	2917.11		
<i>Within locations - repeated measures</i>					
Before vs. After	25653.36	1	25653.36	25.824	0.007
Times <sub>within B vs. A</sub>	79840.78	4	19960.19	19.065	< 0.001
Impact vs. Control × Before vs. After	14042.25	1	14042.25	14.136	0.020
Impact vs. Control × Times <sub>within B vs. A</sub>	38495.22	4	9623.81	9.192	< 0.001
Locations <sub>within I vs. C</sub> × Before vs. After	3973.56	4	993.39	0.949	0.462
Locations <sub>within I vs. C</sub> × Times <sub>within B vs. A</sub> /Error	16751.33	16	1046.96		

Notes: The two tests of impact, *Impact vs. Control* × *Before vs. After* and *Impact vs. Control* × *Times<sub>within B vs. A</sub>*, are both associated with relatively small probabilities. The relatively high probability of the *Locations<sub>within I vs. C</sub>* × *Before vs. After* term demonstrates that catchments performed similarly within the categories of impacts and controls over time.

Data were analysed using SYSTAT for Windows Version 8.03. Two outliers were detected but tests revealed they had no effect on the probabilities of the *F*-tests. Note that use of analyses of variance should always be accompanied by detailed examination of assumptions including that of compound symmetry. We have not reported on whether the data meet these assumptions for the sake of brevity. Readers may wish to check these assumptions themselves and observe the effects that different transformations can have on the *F*-tests!

# LIMING EXAMPLE: REPEATED MEASURES INTERPRETATION

Referring to ANOVA Table

- F test on the interaction of (impact vs control)\*(before vs after) is the key. This tells us if differences between impact and control locations change when we compare the after period to the before period. Here they do. (There is liming effect) (Result 1  $p=0.02$ )
- F test on the interaction of (impact vs control)\*(Times within before and after) is also very important. This shows if the differences between impact and control locations alter within the before and after periods. They do for the after because the effect of the liming is short lived. If liming had had an ongoing effect this component would have been insignificant. (Result 2  $p<0.001$ )

# LIMING EXAMPLE: REPEATED MEASURES INTERPRETATION

To Summarize The Results Of The Tests!

- There is a liming effect and it is statistically significant
- The interaction of the liming effect and time (after) is clear from the second interaction test which is statistically significant
- Therefore the effect of the liming is short lived (not consistent over time after the event, not surprising either of course).

# **LIMING EXAMPLE: EXPERIMENT INTERPRETATION AND CONCLUSIONS**

- **Excellent Replicated BACI Example. Very useful inferences possible based on formal statistical tests.**
- **Lengthy study-6 years (3 before and 3 after) which is good.**
- **High Cost and yet still only 3 replicates of each type of site. These studies are very difficult to do in practice at reasonable spatial scales**

# We Considered in Detail BACI But...

## FOUR BASIC DESIGN TYPES No Randomization

Designs from Weakest to Strongest after some  
perturbation of a system

- After Measures Only on Impact Areas Only
- Before-After Measures on Impact Areas Only
- Control-Impact Areas After Measures Only
- Before-After, Control-Impact Areas Measures (BACI)

Lets think in terms of assessing some human related disturbance but many of the ideas could be relevant in other field study settings.

# **Detecting Ecological Impacts Caused by Human Disturbances on Populations or Communities of Plants or Animals.**

- Other (Usually) Large Scale Perturbation or Manipulation Studies.
- There is a hypothesis of interest and possibly hypothesis testing if replicates possible.
- There is usually no randomization of treatment conditions
- It is easier to focus the discussion by using the terms for impact studies.

# Environmental Impact Assessment

## Examples

### Planned Impacts

- Power Plant Construction
- Suburban Development
- Hunting or Fishing Regulation Change

### Unplanned Impacts

- Oil Spill
- Bush Fire
- Invasion of a disease, or an exotic species

# Environmental Impact Assessment

## Planned Impacts

Before and After Measurements Usually Possible

Better Chance to Find Controls?

## Unplanned Impacts

Only After Measurements Possible (unless very lucky)

# **FOUR BASIC IMPACT DESIGNS MENTIONED EARLIER**

**Presented in Order of Weakest to Strongest.**

- After Measures Only on Impact Areas
- Before- After Measures on Impact Areas
- Control-Impact Areas After Measures Only
- Before-After, Control-Impact Areas Measures (BACI)

# AFTER ONLY DESIGNS ON IMPACT AREAS

- Really bad situation to be in but may happen often for unplanned impacts!!
- No Randomisation, No Control Sites, No Before Measures
- You would have to base any idea of change in the system on subjective view of what the population or community or ecosystem was like before.
- You could make some progress by studying the recovery process by a **monitoring program** way into the future and looking at the **time series of responses**.

# BEFORE-AFTER DESIGNS ON IMPACT AREAS

- Measure response on impacted sites before and after the impact.
- No randomisation
- No control sites
- **Confounding of any temporal changes with the impact effect.**
- May be only reasonable design (Dam Study of Hightower last year) for some planned impacts where control sites are impossible to find..

# BEFORE-AFTER DESIGNS ON IMPACT AREAS ANALYSIS

Paired Plots

Paired T Test (Assumes Normality)

$$D_i = (X_{IAi} - X_{IBi}) \quad i = 1, \dots, n$$

$$H_0 \quad \mu_D = 0$$

$$H_1 \quad \mu_D \neq 0$$

$$T = \frac{\bar{D}}{\sqrt{\frac{s_D^2}{n}}} \quad df = (n - 1)$$

Calculate p values etc

**One Time Point or Mean Before vs After Plots over Time**

# BEFORE-AFTER DESIGNS ON IMPACT AREAS

- Notice how the T Test we did before is seductive and looks just the same.
- Remember the confounding of impact and some other time change is crucial weakness!

# CONTROL- IMPACT DESIGNS AFTER IMPACT ONLY

- Measure response on control and impacted sites after the impact only.
- No randomization
- No before impact measurement.
- Confounding of the impact effect with inherent control site vs impact site differences.
- Match the control and impacted sites as much as possible or use analysis of covariance to try to adjust out differences
- May be no other alternative if populations not studied earlier and impact is unplanned.

# CONTROL- IMPACT DESIGNS AFTER IMPACT ONLY

Paired Plots

Paired T Test (Assumes Normality)

$$D_i = (X_{IAi} - X_{CAi}) \quad i = 1, \dots, n$$

$$H_0 \quad \mu_D = 0$$

$$H_1 \quad \mu_D \neq 0$$

$$T = \frac{\bar{D}}{\sqrt{\frac{s_D^2}{n}}}, \quad df = (n - 1)$$

Calculate p value etc.

ST 511 Material.

**One Time point or Mean Control plot vs Impact plot  
over Time**

# CONTROL- IMPACT DESIGNS AFTER IMPACT ONLY

- Again notice how seductive it is to do the T Test!!
- Again there is important confounding. Here inherent differences between control and impact sites are confounded with the impact effect.

# BACI DESIGNS AGAIN

- Generalised Paired T test we talked about earlier and Nathan Tarr presented
- Finally we don't have serious confounding issues even if we don't randomise.
- Therefore Finally a Really Good Design!

# Concluding Remarks on Expts and Quasi Expts

- **Classical Experiments**

Clearly defined, very strong inference

May have to be done in microcosms or on a small scale

- **Quasi Experiments (wide range of types)**

Weaker inference, BACI is the best but it is not always feasible. Replicated BACI is the best.

Many Quasi Expts don't have adequate replication and are only run because better designs not possible.

Be clear about what the unit is so that one can therefore be clear about whether one has replication or only pseudoreplication.

# Assessing Recovery Following an Environmental Accident.

- Parker and Wiens (2005) Ecological Applications 15, 2037-2051.
- Very good discussion of different study designs. Related to our earlier discussion on BACI designs and “weaker” alternatives

Read over Additional Example of  
BACI if Interested: Slides Given  
Here.

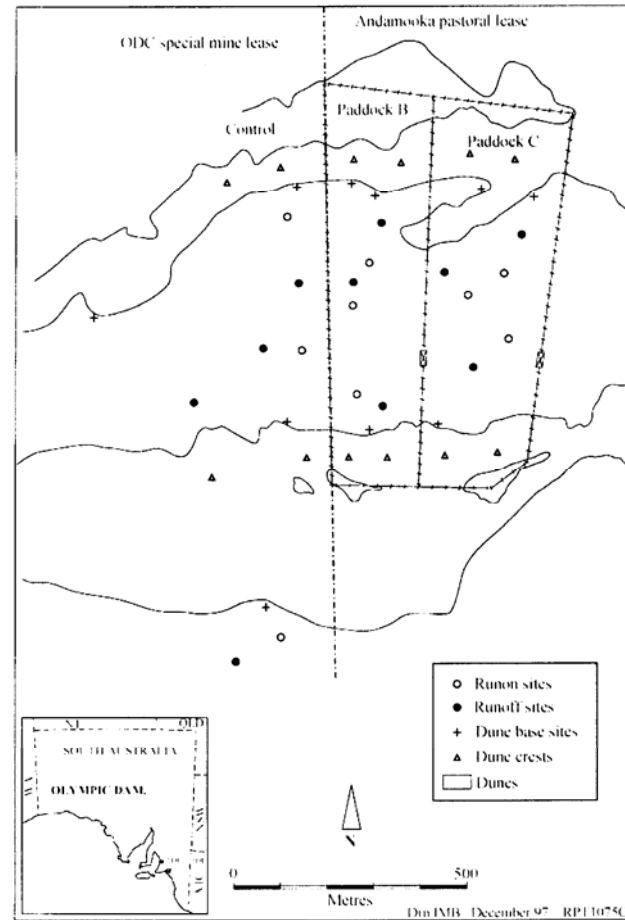
# BACI DESIGN EXAMPLE: EFFECT OF GRAZING ON ANT COMMUNITIES

- Read and Andersen (2000). *J of Arid Environments* 45, 231-251.
- Read critically the methods- Are there any weaknesses/problems with the design as implemented here?
- Interpretation of Results?
- Discussion? Better Designs?

## Methods

### Study site

This study was conducted near Olympic Dam (30° 26' S; 136° 57' E), approximately 530 km north of Adelaide in South Australia (Fig. 1). The landscape is dominated by a dissected silcrete plain, overlain by parallel east-west trending sand dunes. Dunes are principally vegetated by tall shrubs and low trees including *Acacia ligulata*, *Acacia*



**Figure 1.** Location of Olympic Dam and study sites.

# Methods: Very Complex Expt

“Treatment” Structure at the Paddock Level..

Control-1

Grazed-2 (Paddock B, Paddock C) short intense bursts in June and Dec 1995

Paddocks not **randomised** to treats & not **interspersed**.(Fig 1)

In most analyses results for the two grazed paddock are presented separately so there is **no true replication**.

Within paddock sampling sites are used as replicates in repeated measures ANOVA. (see justification top 235, top 236). Example of **pseudoreplication**

# Methods: Very Complex Expt

“Treatment” Structure Within Paddocks. (habitats)

Dunes 4 sites

Swales (Subhabitats)

Dune Base -4 Control, 3 Grazed paddocks

Run Off - 4 Control, 3 Grazed paddocks

Run On- 4 Control, 3 Grazed paddocks

# Methods: Very Complex Expt

## Sampling

Used Pitfall traps

Ants counted by genus or species and assigned abundance classes.

Some analyses lumped into functional groups

## Timing

Pre –Feb 95

Post –Nov 95, Dec 95, Feb 96, Nov 96, Jan 97

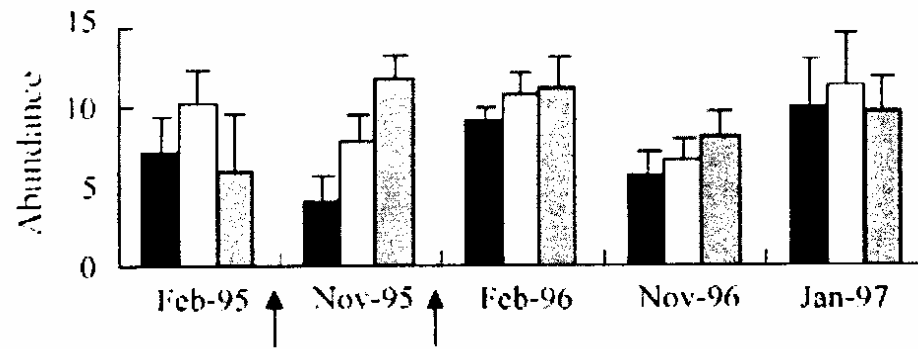
**Recall-**Grazing in June 95 and then again briefly in 95 Dec

# Analysis

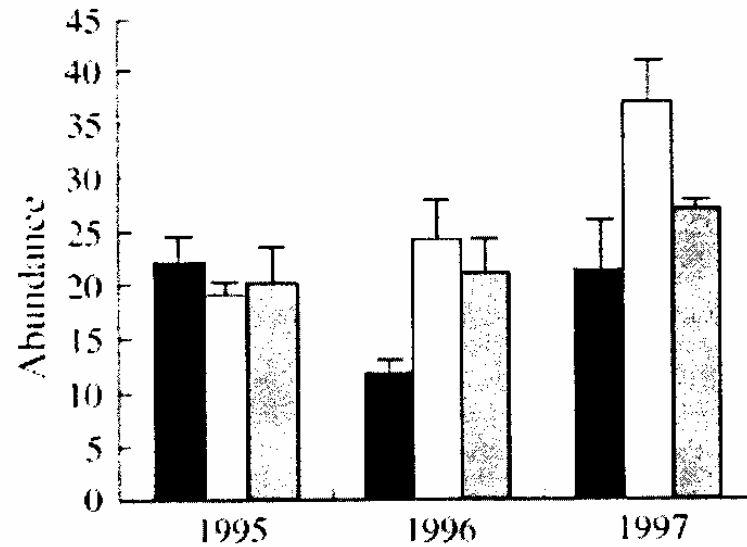
They state they use repeated measures ANOVA.

Not totally clear to me how they did it.

They did treat each habitat separately in the analyses



**Figure 7.** Mean (+ 1 S.E.) total abundance of Hot-climate Specialists at dune-base subhabitat sites. Arrows indicate grazing pulses: ■, control; □, paddock B; ▨, paddock c.



**Figure 9.** Mean (+ 1 S.E.) abundance of Hot-climate Specialist ants at dune sites: ■, control; □, paddock B; ▨, paddock c.

# **BACI EXAMPLE: EFFECT OF GRAZING ON ANT COMMUNITIES: RESULTS**

After Grazing

Generalised Myrmicinae increased on swales

Hot climate specialists increased on dunes

# **BACI EXAMPLE: EFFECT OF GRAZING ON ANT COMMUNITIES: DISCUSSION**

- Interesting Results and probably important but there are limitations of their generality.
- Even within the BACI framework there are design issues
  - Replication issues
  - Spatial Scale issues
  - Randomisation and Interspersion Issues
- There are also analysis issues (methods not clearly described).
- **This is not to say the study wasn't worth doing.**