

Lecture 27

- ◆ Meta-Analysis Reflections
- ◆ Multivariate Analysis Techniques

Final Proposals and Exam

- Preferred Due Date for both the Final Proposal and the short take home exam is April 30, 2008.
- I will be away Tues and Wed so if this causes problems on the take Home Exam you can hand it in on May 1 or 2nd.

Meta-Analysis Reflections

Types

Literature

Designed Large Scale Spatial Studies

Both these types analyses are becoming more common and will be used even more in the future.

Meta-Analysis Reflections

I perused Ecology 2008. There were 3 very large studies in the 3 issues out so far.

Hillebrand(2008). 89:165-173.

LeBauer and Treseder (2008). 89: 371-379.

Kaplan et al. (2008). 89: 392-406.

I also found various studies in the fisheries and wildlife literature.

Meta-Analysis Quick Review

Formal Meta Analyses

- Importance of combining studies to see what the overall weight of evidence for a particular hypothesis is.
- Serious issues of how studies are chosen to combine. Perhaps done by one research group but most often have to be found from **published literature**.
- In the future researchers will collaborate to do multi-site studies and use meta analyses to study large problems especially large spatial scale problems. It is already happening.

Steps in a Meta-Analysis

- Specification of the research question
- Definition of the effect size metric to be used
- Select the Data/papers to be included in the meta-analysis according to some criteria.
- Select Statistical Approach/ Model to be Used
- Make Conclusions: evaluate limitations due to using published data (missing data, lack of independence, publication bias, research bias etc)

Effect Size Metrics

- **Difference of means** (treatment mean – control mean)
- **Ratio of means** (treatment mean/control mean)

These two metrics are often standardized to take account of different variances between studies

- Another metric is the **correlation coefficient** between two variables. Before combining across studies the correlation coefficient is usually transformed to normality
- Others may be used but these are the very common ones

Data Selection Criteria

- One has to set up criteria for which studies to include in the meta-analysis.
- Eglund et al. (1999) in the special volume have a very good example where the criteria used for inclusion of studies makes a difference to the outcome.

Statistical Modelling Approach: Weighted Mean Effect Size

- Each study has a d_i (standardised effect size) with its v_i (variance). The key point is that the studies vary in their precision of the effect size variance.
- In simple case take the weighted mean

$$\bar{d} = \frac{\sum_{i=1}^s w_i d_i}{\sum_{i=1}^s w_i}$$

Here $w_i = 1 / v_i$

and s is the # of studies.

- Will not get into the variance calculations here as they are complex.

Statistical Modelling Approach: Handling Covariates

- Of course there may be differences in the true effect size in a study depending of one or more covariates and understanding the relationships between the effect size and the covariate is the key interest.
- Sometimes break the studies up into subgroups based on the covariates and compare them. Maybe an effect is positive in some subgroups and negative in others.
- Alternately one could regress the effect size against the covariate! This is the approach used by Dunn(2004) which we will look at later in the lecture.

Limitations and Problems with Data

- Incomplete Reporting and Missing Data
- Lack of Independence of Studies
- Publication Bias
- Research Bias

Incomplete Reporting and Missing Data

- Many studies especially older ones suffer from inadequate data being reported.
- If there is inadequate reporting of the variances then the weighted analyses cannot be used. Use unweighted versions but the analysis is much weaker!
- Need better data reporting. (Appendices and data archives to keep the paper size manageable).

Lack of Independence

- The key issue here is that if one researcher has a series of separate studies they may give more similar results than a study by a different researcher.
- Also for studies on similar taxa then studies on same taxa more similar than studies on different taxa if one pools over taxa.
- Perhaps could use hierarchical modelling approach but it would be complex.

Publication Bias

- Another very important complication to all meta analyses based on the literature is that studies with larger p values (thus “insignificant”) may not even get published.
- Solutions-look if effect size is correlated with its standard error. Alternately build more elaborate models.

Research Bias

- Similar idea to publication bias. See p 1148. The tendency to perform experiments on organisms or under conditions in which one has a reasonable expectation of detecting statistically significant effects.
- This could cause bias if we are wanting to apply or inferences more generally (say to a wider set of taxa).

Marine Enrichment Experiments: Overall Results Fig 2

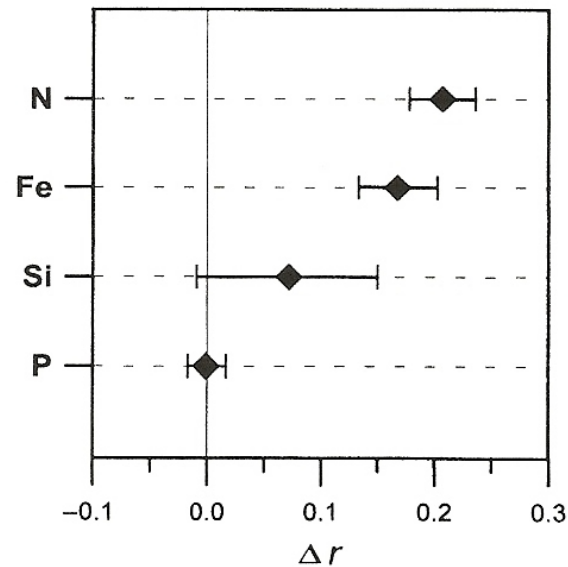


FIG. 2. Effects of nutrient addition on phytoplankton growth, as measured by Δr , the change in per unit (per gram; per unit carbon, or per chlorophyll *a*) growth rate of an algal assemblage following the addition of surplus nutrients. Results give responses for each nutrient added singly to phytoplankton assemblages and show, using an unweighted analysis with resampling procedures, that nutrients varied in their effect on phytoplankton growth ($P = 0.002$). Error bars represent 95% confidence intervals of Δr based on the resampling procedures with 5000 iterations. N denotes experiments enriching with nitrogen, P denotes phosphorus addition, Si denotes silicate addition, and Fe denotes iron addition. The means are based on 148 (N), 114 (P), 35 (Fe), and 6 (Si) experiments.

Example Meta- Analyses: Rob Dunn

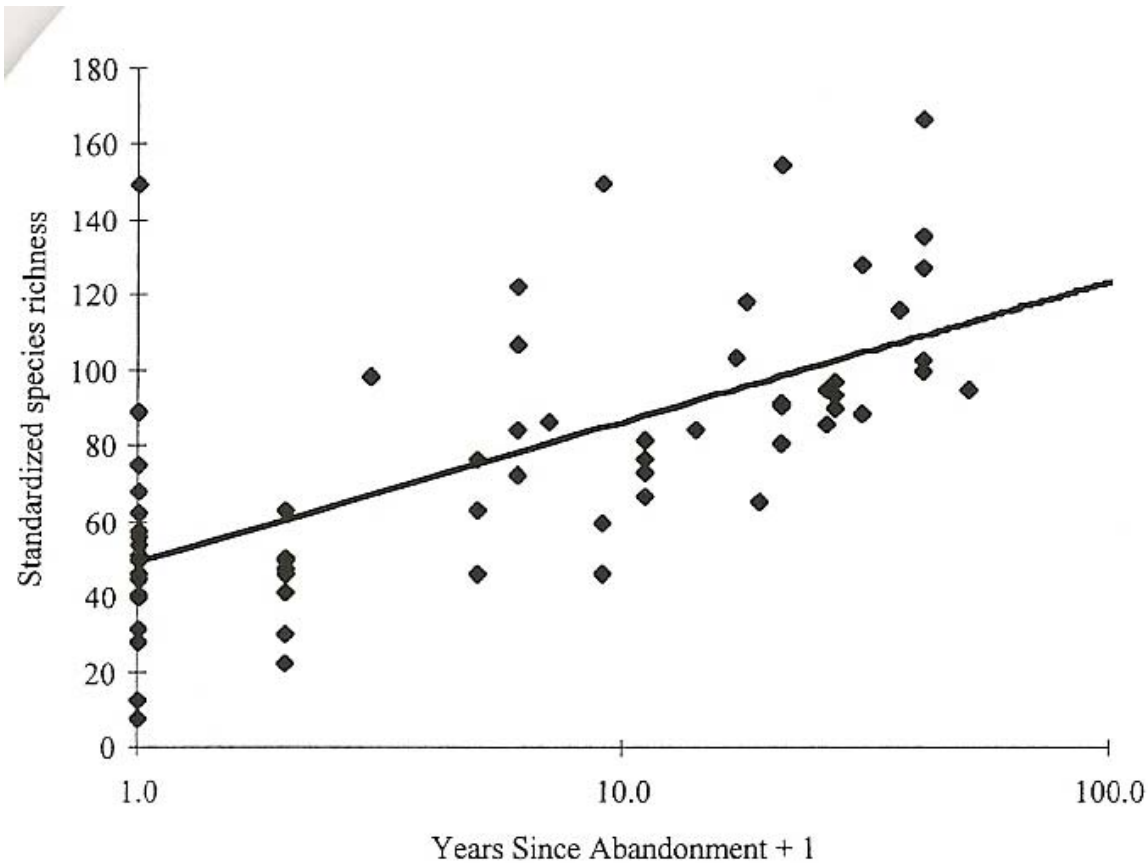
Dunn (2004) Conservation Biology 18, 302-309. Recovery of Faunal Communities During Tropical Forest Regeneration.

- 33 papers found with research at 22 sites, this lead to the use of 39 data sets. Some sets were different taxons at the same sites but the data sets were treated as though they were independent. See Appendix 1 for a summary of all the data sets.
- One Metric used was standardized species richness for a taxon which is
(Species richness of site/ species richness of mature forest).
- There were a variety of measurement problems on estimating species richness consistently across the data sets and also on defining what was a mature forest.

Example Meta- Analysis: Rob Dunn

- One objective was to relate standardized species richness (y) to $\log(x+1)$ where x is age since succession back to forest began.
- Linear regression used to see how quickly there was recovery. See Figure 1. Recovery time estimated to be 23 years in terms of richness (much longer for other metrics we do not consider here)
- He then looked at the ant studies(10) and the bird studies(10) separately. The results were very similar (Figure 2).

Dunn (2004)



Example Meta- Analysis: Rob Dunn

I think this a very interesting study with important results. It also shows clearly some of the problems of conducting a meta-analysis. Some limitations were:

- Data standardization issues because studies measured and reported quantities differently. Further it was not always easy to be sure what a mature forest was.
- No weighting of data sets possible although they clearly have different variances within sets. This reduces the power of tests and the precision of estimators (slope of the regression line).
- Data are treated as independent points in the regressions.
- Publication Bias and Research bias have unknown effects.

Recommendations

- Use weighted analyses if at all possible.
- If not possible use unweighted analyses which will have lower power but one doesn't have a choice.
- Design new meta analyses so the studies in them can be weighted or ideally have them of equal weight by design.

Large Scale Spatial Studies

- Sometimes researchers do large spatial scale studies by combining resources across groups. Rob Dunn is involved in such efforts.
- The advantage of this approach is that it gets away from the problems of lack of uniformity and publication bias that comes when one relies on standard literature based Meta-Analyses

Are Meta-Analyses Used in Applied Wildlife and Fisheries Studies?

- Yes, I found quite a few..
- A study of large spatial scale combined with BACI on chronic wasting disease in mule deer.
- A study that does a meta analysis on quail survival estimated from telemetry studies.
- A fisheries study on hooking mortality of trout.
- A fisheries study on meta-analysis of stock recruit relationships.

Meta-BACI Paper

Conner et al. (2007). A Meta-BACI Approach for Evaluating Management Intervention on Chronic wasting Disease in Mule Deer. *Ecological Applications* 17: 140-153.

Background

- Emerging infectious diseases and their effect on wildlife and human health
- Goal to evaluate the effectiveness of management (intense localised culling using sharp shooters) to reduce the prevalence of chronic wasting disease in mule deer in Colorado.
- Paired Control and Managed Sites studied in a BACI design.

Background

- Size of units averaged 98km² for managed and 139 km² for controls.
- Culled average of 52 deer per site.
- Prevalence varied widely but was about 0.07 on average.

Metric

Metric was change in disease prevalence adjusted for time effects using the standard BACI approach we considered earlier in class.

$$\hat{d}_i = (\hat{p}_{mb} - \hat{p}_{ma}) - (\hat{p}_{cb} - \hat{p}_{ca})$$

\hat{p}_{ij} – *estimated prevalence*

m – *managed*

c – *control*

b – *before*

a – *after*

Metric: Weighted Mean and Analysis

$$\hat{d}_i = (\hat{p}_{mb} - \hat{p}_{ma}) - (\hat{p}_{cb} - \hat{p}_{ca})$$

$$\hat{d}_w = \sum_1^n w_i \hat{d}_i / \sum_1^n w_i$$

w_i – reciprocal of the variance

One Sided Paired t test

Wilcoxon Signed rank test.

Results

- Effect size was 0.03 with $SE=0.03$. So effect size was in the “right direction” but--no stat evidence of the culling having an effect ($p=0.208$ from the t test)
- They did some simulations to look at power.
- I wont go into that aspect of the study as it is very complex but basically it looks to me like power in the current study was low.
- These kind of studies will be necessary in the future and will need to be well designed with better power. I mention the paper for that reason.

Quail Telemetry Survival Analysis

Guthery and Lusk (2004). Radio-telemetry studies: are we radio-handicapping northern bobwhites. *Wildlife Society Bulletin* 32: 194-201.

Quail Telemetry Survival Analysis

- Concern that radio-tags may be causing extra mortality on quail so that survival estimates from such studies biased low and are therefore very misleading. They note researchers on other species have had similar concerns.
- 58 studies with daily survival rate estimates obtained and converted to annual estimates.
- They concluded that most of the estimates were biased low by running population models and showing that λ was way less than 1 in many cases.

Quail Telemetry Survival Analysis

Folk et al. (2007) JWM dispute their findings for a variety of reasons:

- inappropriate extrapolation from daily to annual survival rates
- lack of independence of the estimates from the different studies
- inappropriate modelling techniques

Palmer and Wellendorf (2007) JWM ran studies comparing banded birds to banded and telemetered birds and found no difference in the estimates.

Even if the original study flawed the resulting discussion and research has been valuable.

Trout Hooking Mortality Meta-Analysis

Taylor and White (1992). A Meta-Analysis of Hooking Mortality of Nonanadromous Trout. North American Journal of Fisheries Management 12: 760-767.

Trout Hooking Mortality Meta-Analysis

- This is a classic meta-analysis study based on the published literature.
- Hooking mortality of trout when subject to catch and release fishing.
- 18 studies included in the meta-analysis.
- pen studies used to estimate the short term (3 day) hooking mortality. (Note would not include predation mortality component).
- They looked for differences in hooking mortality based on bait vs lures, species of trout, hook type, water temperature etc.
- Not much discussion of limitations of meta-analysis.

Bayesian Meta-Analysis of Stock Recruit Relationships West Coast Rockfish

Dorn (2002). Advice on West Coast Rockfish harvest rates from Bayesian Meta-Analysis of Stock-Recruit Relationships. North American Journal of Fisheries Management 22: 280-300.

Bayesian Meta-Analysis of Stock Recruit Relationships West Coast Rockfish

- Concern over the steep declines of Rockfish stocks on the West Coast.
- Long term(7-40 yrs) stock-recruit data for 11 stocks in the Northeastern Pacific Ocean.
- Very complex modelling which I did not have time to review. What I know about these models is just enough to be dangerous.
- Fisheries students may find the paper of some interest.

Final Reflections on Meta Analysis

- Much potential for the future but require consistent commitment. Some problems cannot be studied any other way.
- Huge Practical problems to run them well (the chronic wasting disease deer study involved a large spatial scale and a long time period for the study, the quail telemetry study may have ended up with highly biased estimates).

Extra Summary Slides You May find Useful

Overview: A Useful Dichotomy?

- ◆ What does Multivariate Mean?

- ◆ Y-Univariate, X-Multivariate

 - Linear Models (many types, we shall review quickly)

- ◆ Y-Multivariate

 - “True” Multivariate Techniques (many types we shall review superficially)

Overview on Handling Multivariate Data

- ◆ Types of Linear Models

 - Traditional Anova Models

 - Regression Methods

 - Analysis of Covariance

 - Spatial Methods

 - Time Series Methods

- ◆ “True” Multivariate Techniques

 - Cluster Analysis

 - Principal Components Analysis and Factor Analysis

 - Canonical Correlations Analysis

 - Discriminant Analysis

 - Many Others

Types of Linear Models

Simple ANOVA models with class variables as the independent variables

Simple Regression models with continuous variables as the independent variables

Analysis of Covariance (class and continuous variables)

Spatial Methods (regression-spatial error structure)

Time Series Methods (regression- temporal error structure)

Types Linear Models-Simple ANOVA

Simple ANOVA models with class independent variables

Uses are to include treatment structure, blocks and other aspects of the experimental design in:

True Experiments

Quasi Experiments-by extension, need to be careful here as although widely used they may not be valid.

ANOVA Models for Simple Experimental Designs

Completely Random Design- Treatments are allocated randomly to the experimental units. Usually equal replication is used

$$y_{ij} = \mu + \tau_i + \varepsilon_{ij}$$

Randomised Complete Block Design- Experimental units are allocated into homogeneous blocks. Each treatment randomly allocated to one experimental unit in each block

$$y_{ij} = \mu + \tau_i + \beta_j + \varepsilon_{ij}$$

ANOVA Models More Complex Experimental Designs

Factorial Treatment Structure

Split Plot Designs

Repeated Measures Designs

Types of Linear Models: Multiple Regression

Linear Regression models with continuous variables.

Usually multiple X variables.

Uses: In Observational studies to study relationships between variables when one variable is of primary importance

Discussed in some detail earlier in semester. Emphasis was placed on key assumptions. (Multi collinearity and non independent error structures)

Simple Linear Regression Method

$$Y_i = \mu \{ Y | X \} + \varepsilon_i$$

$$\mu \{ Y | X \} = \beta_0 + \beta_1 X$$

Y-Dependent Variable

X- independent variable

$\mu\{.\}$ –is the mean function and is **conditional on the X's. This is very important!!**

β_0 is intercept and β_1 is slope. ε -independent Normal errors with constant variance is the standard form..

Multiple Regression Methods

$$Y_i = \mu\{Y \mid X_1, X_2, \dots, X_p\} + \varepsilon_i$$

$$\mu\{Y \mid X_1, X_2, \dots, X_p\} = f(X_1, X_2, \dots, X_p)$$

Y-Dependent Variable

X- independent variables-how to chose them is a key question?

$\mu\{.\}$ –is the mean function and is **conditional** on the X's

f- often a linear function of X's but not always.

ε -often independent Normal errors with constant variance.

Types of Linear Models: ANCOVA

Analysis of Covariance (class and continuous variables)

Mixes ANOVA and Regression in One Analysis

Used in Experiments to control for an important auxiliary variable

Particularly important to use in Quasi experiments when randomization of treatments is not possible.

Analysis of Covariance Method

$$Y_{ij} = \mu + \tau_i + \delta_j + \beta X + \varepsilon_{ij}$$

Y_{ij} -Dependent Variable

τ_i is the treatment effect and δ_j is the block effect

β is slope and is constant over all treatments

X_{ij} - independent continuous variable

This model mixes ANOVA and Regression. Goal to adjust for a covariate so one can test a “treatment” effect at a constant level of the covariate.

Types of Linear Models: Spatial Methods

Extends regression models to allow a spatial error structure- spatial autocorrelation

Uses- Observational studies where data is collected on some regular or irregular spatial grid.

Simons Lecture- not much detail given in this class

Types of Linear Models: Spatial Methods

Think of Points on a spatial grid (i, j) in two dimensions

$$y_{ij} = \beta_0 + \beta_1 X_{ij} + \dots + \varepsilon_{ij}$$

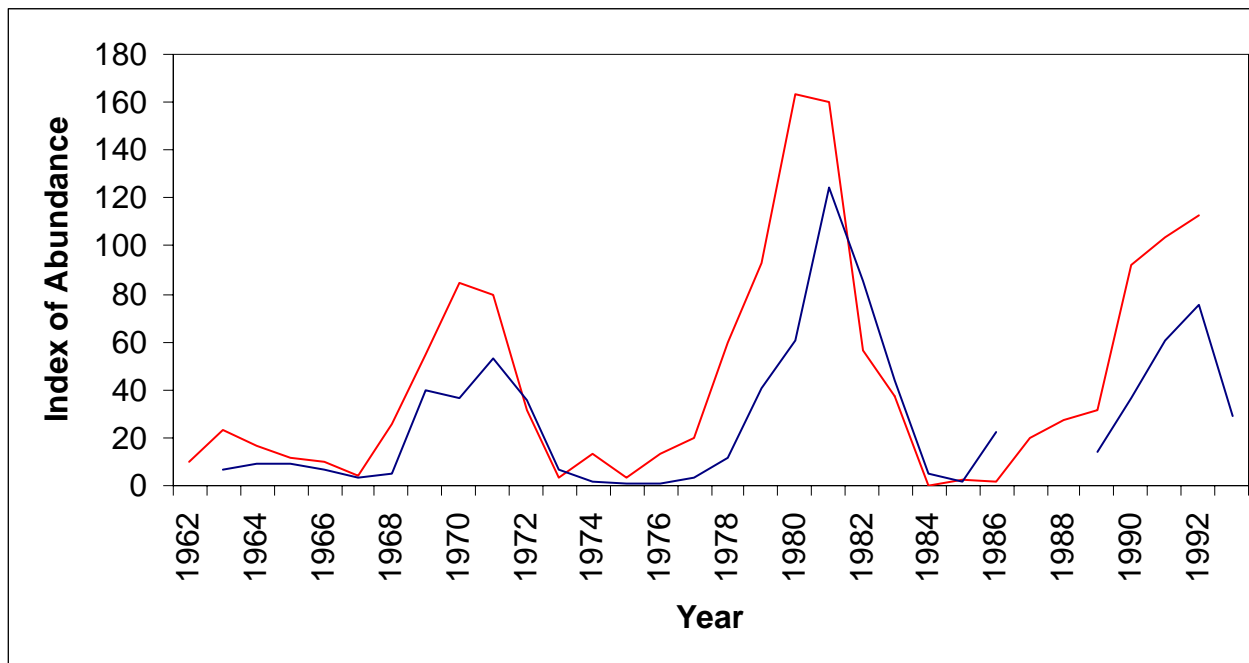
$\varepsilon_{ij}, \varepsilon_{i'j'}$ correlated with the correlation

depending on how far apart the points are

Types of Linear Models: Time Series

Extends regression methods to allow a temporal error structure-temporal autocorrelation.

Uses: Long term research and monitoring observational studies.



Types of Linear Models: Time Series

Single time series- single species studies

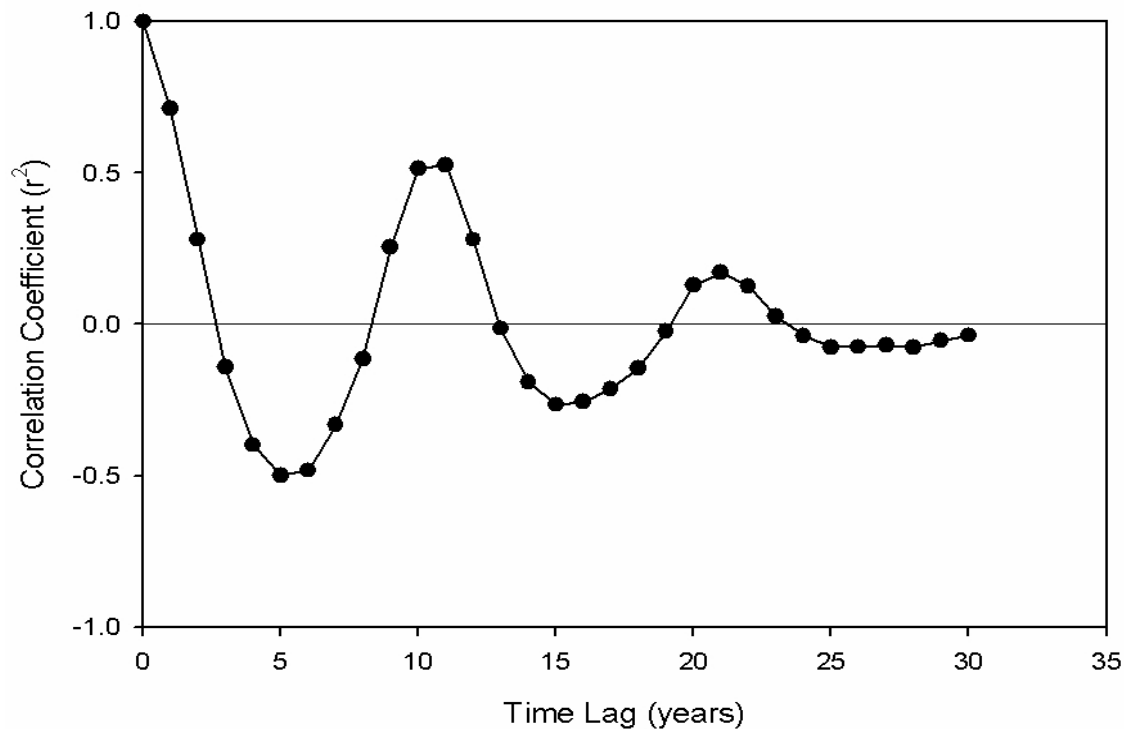
Multiple time series-community ecology

Intervention Analysis –time series before and after a change point due to an impact or manipulation of some kind

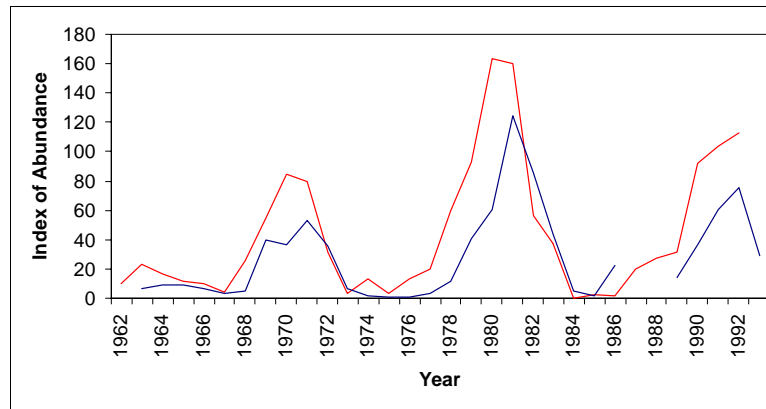
No detail in this class. Very useful if one can get enough years of data to do formal analyses. Needs a commitment to long term research.

Descriptive Analysis: Correlograms (Sexton Slide)

Autocorrelation analysis: plots correlation between a population's size at time, t , and its size at some lag time interval



Types of Linear Models: Time Series



Formal Analyses- Many Types of models-ARIMA Models

AR(1) Model as a Simple Example

$$y_t = \beta_0 + \beta_1 X_1 + \dots \beta_p X_p + \phi_1 y_{t-1} + \varepsilon_t$$

Overview on Handling Multivariate Data

- ◆ Types of Linear Models

 - Anova,

 - Regression

 - Analysis of Covariance

 - Spatial Methods

 - Time Series Methods

- ◆ “True” Multivariate Techniques

 - Cluster Analysis

 - Principal Components Analysis and Factor Analysis

 - Discriminant Analysis

 - Many Many Others

Important Reference

Useful reference and software:

McCune and Grace (2002). Analysis of Ecological Communities. MjM Software Design –PC-ORD.

Multivariate Analysis

- ◆ **Cluster Analysis**
- ◆ **Principal Component Analysis**
- ◆ **Discriminant Analysis**
- ◆ **Other Techniques**

Overview on Handling Multivariate Data: Many Goals

- ◆ Looking for Pattern
- ◆ Dimension Reduction
- ◆ Discrimination Between Groups
- ◆ Other Goals

Cluster Analysis: Objectives

- ◆ **Classify sampling units into homogeneous groups or clusters based on minimising “distance” between units in multidimensional space.**
- ◆ **Cluster analysis is done in a hierarchical way: usually starting from the closest units and working out to larger distances.**
- ◆ **To relate the clusters to independent biological groups(habitats, species etc depending on the application.)**

Cluster Analysis: Objectives

- ◆ **Generally one is looking for pattern here.**
- ◆ **Classify sampling units into homogeneous groups or clusters based on minimising “distance” between units in multidimensional space.**
- ◆ **Cluster analysis is done in a hierarchical way: usually starting from the closest units and working out to larger distances.**
- ◆ **To relate the clusters to independent biological groups(habitats, species etc depending on the application.)**
- ◆ **There are many algorithms used. A good ref is McCune and Grace (2002) Chapter 10 and 11.**

Cluster Analysis: Displays

- ◆ **A Triangular distance matrix may be constructed**
- ◆ **A dendrogram may be constructed to show the pattern in how the subjects group into clusters as a function of distance and then how the initial clusters form larger and larger clusters.**

Cluster Analysis: Distance

- ◆ **In the simplest cases the variables are continuous and distance has its standard meaning.**

Cluster Analysis Wentworth Example

- ◆ **Realistic example in terms of scope.**
- ◆ **Clustering of Plots where the data for each plot is the % cover of each of 93 plant species**
- ◆ **Objective was to calculate dendrogram and then see how the pattern matched up with different predefined habitats**

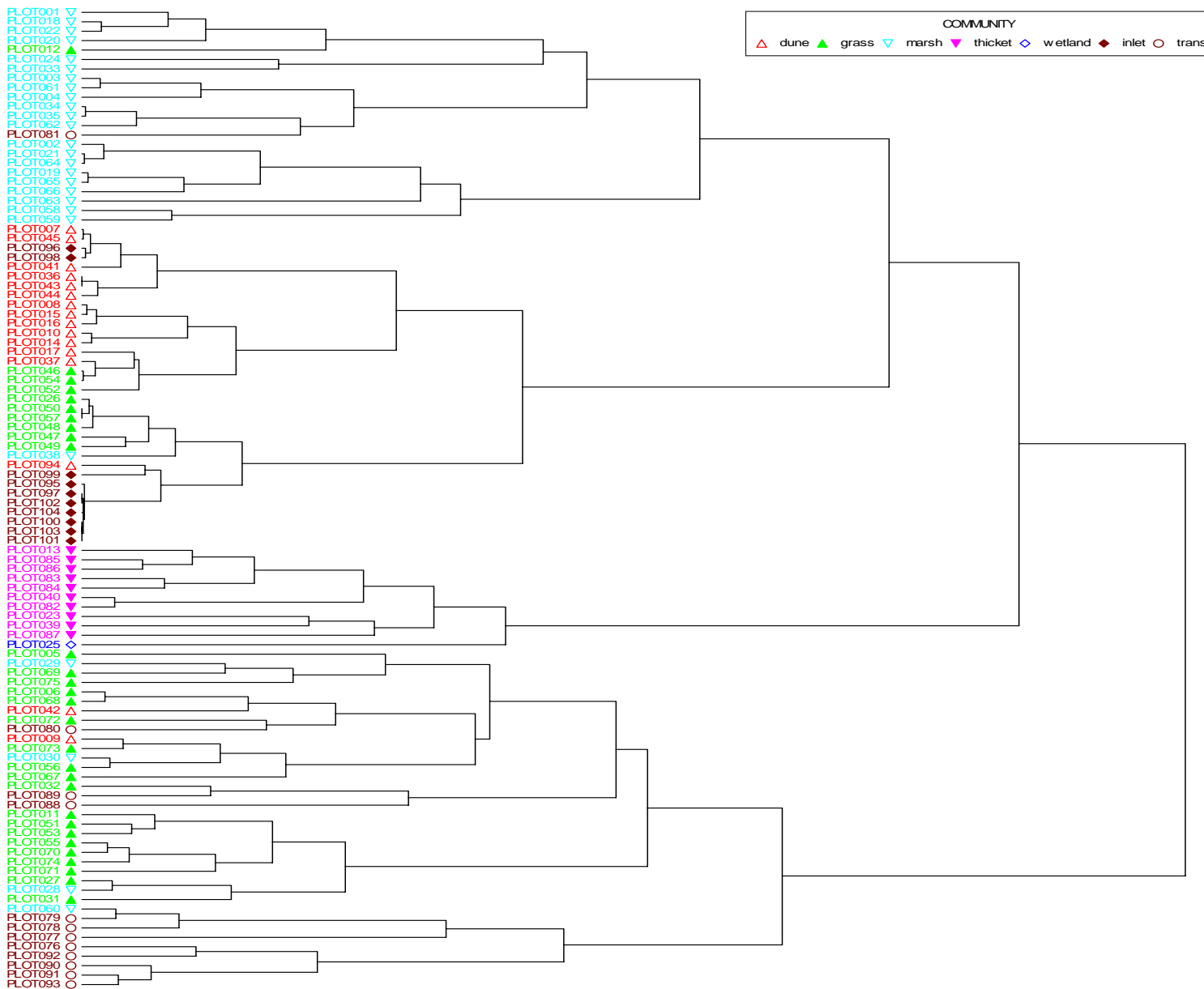
Bird Island Cover Data

Distance (Objective Function)

5E-01 2.3E+03 4.6E+03 6.8E+03 9.1E+03

Information Remaining (%)

100 75 50 25 0



Cluster Analysis: Programs

- ◆ **There are an enormous number of different methods of cluster analysis available**
- ◆ **SAS Proc CLUSTER**
- ◆ **SAS Proc TREE (dendrogram)**

Principal Component Analysis: SAS Proc PRINCOMP

(X_1, X_2, \dots, X_p) dimensional vector of data with n sample size.

The Objectives are:

- to find the p orthogonal (independent) linear functions of the original X 's that explain all the variation in the original data.
- to try and markedly reduce the number of important dimensions in multiple dimensions data if a small subset of the principal components explains almost all the variation.
- to interpret the PC's found biologically from the pattern in the coefficients. (For example, perhaps one component is predominately understory variables whereas another is predominately canopy in a forest habitat study)

Principal Component Analysis: Ordination Methods

McCune and Grace (2002) Part 4 Present
PCA as the first of a whole set of ordination
methods which include

PCA

Rotation methods (Factor Analysis)

Multi Dimensional Scaling

Correspondence Analysis.

Principal Component Analysis

Some Caveats

- ◆ **Be careful of the assumptions**
- ◆ **Useful technique but sometimes the components don't make biological sense**
- ◆ **Exploratory data analysis rather than testing hypotheses?**

A Combination Approach

- ◆ **PCA Regression –some biologists prefer to use the original X variables whereas others prefer to use the PCA as composite X variables. I can see arguments both ways.**

Discriminant Function Analysis

Objective:

- ◆ To find a mathematical rule involving multivariate responses that best discriminates the sampling units into distinct pre existing groups.
- ◆ To minimise the misclassification rates

SAS Proc DISCRIM

Discriminant Function Analysis

Approaches:

- ◆ **Fishers Linear Discriminant Method**
- ◆ **Logistic Regression**

Validation:

- ◆ **Training Set**
- ◆ **Cross Validation set-How well does it classify?**

Discriminant Function Analysis: Example

Fisher (1936) Iris data-described in the examples of
SAS Proc DISCRIM

- ◆ 50 iris specimens of each of three species. The multivariate data has 4 variables sepal length, sepal width, petal length, petal width.
- ◆ Fisher Discriminant function used to see how well the function can separate the specimens into species

Discriminant Function Analysis: Example Misclassification Rates

SETOSA	VERSICOLOR	VIRGINICA
50	0	0
0	48	2
0	4	46

Discriminant Function Analysis: Lots of Uses in Ecological Research

- ◆ Sample from Populations or Species and see how well various phenotypic variables enable one to distinguish between the groups.
- ◆ Are they distinct popns or species or not? How much do they overlap in these variables?
- ◆ McCune and Grace (2002) Chapter 26. Part of a section on comparing groups