Course Goals

1. Give you a working familiarity with SEM
2. Decide when SEM is right for you
3. Understand the process of model creation, evaluation, and revision
4. Be able to implement SEM in R
Schedule for the Week

M – Introduction to SEM
  Model Building
  Piecewise Fitting

T – SEM with Likelihood
  Model Comparison

W – Multigroup Models
  Latent Variables

Th – Composite Variables
  Advanced Topics

F – Open Consultation

Typical Day

9:00 - 10:30 Lecture/Lab I
10:30 - 10:45 Break!
10:45 - 12:00 Lecture/Lab II
12:00 - 13:00 Lunch
13:00 - 14:30 Lecture/Lab III
14:30 - 15:00 Break!
15:00 - 16:30 Lecture
16:30 - 17:30 Work with Your Data

Where You can Learn More about SEM


also, see www.structuralequations.org

Software for SEM

1. R with lavaan, sem, or openMX libraries – flexible, can solve models piecewise or using covariance analysis. Many options.

2. AMOS – most user friendly, but, point and click

3. LISREL – original software. Still being updated with many advanced features

4. EQS – competitor to LISREL, has REQS package

5. MPLUS – favorite of advanced users, but, black-boxes many processes

6. WinBUGS, JAGS, or OpenBUGS – VERY flexible. VERY complex. Time to get your Bayes on!

7. And more…
Who am I?
Who are you? Why are you here?

Introduction Outline
1. What is SEM?
2. From ANOVA to SEM
3. History!
4. SEM as Part of a Research Program

The Scientific Enterprise is Influenced by our Statistical Methodology

The Scientific Enterprise
SEM is a form of Graphical Modeling

The Structure in SEM implies CAUSALITY

SEM: The use of two or more structural equations to evaluate direct and indirect effects in a system

Simple Idea to Attack Complex Systems
SEM is a Framework

We use statistical and mathematical tools within the SEM framework to build scientific understanding about the multiple processes operating in systems.

SEM as a Unifying Process

Theory

Model Specification

Measuring & Sampling

Estimation

Assessment of Fit

Interpretation

Model Modification

SEM as a Unifying Process

After Grace & Bollen 2005

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Field-based Evidence for the Importance of Small Herbivores in a Seagrass Ecosystem:
An Examination Using Structural Equation Modeling
Matthew A. Whalen¹, J. Emmett Duffy¹, James B. Grace²
¹ - Virginia Institute of Marine Science
² - USGS
Introduction/Questions

Are seagrasses controlled by bottom-up forces or trophic cascade?

Subtext: Is nutrient runoff or overfishing causing seagrass declines?

Field Experiment

1. Investigate proposed food-web interactions
2. Test the relative impact of top-down and bottom-up forces

Manipulation: Nutrients X Grazers

Location: Cuba Island
- nearly monospecific eelgrass bed
- constant depth
- large enough for experiment

Duration: Summer 2009 for 6 weeks

Experiment being replicated around the world! ZEN!

Experimental Reduction of Small Herbivores

Experimental Design:

Treatments:
- pesticide to reduce crustacean grazers
- nutrient addition
- combination
- controls

8 reps @ 5 trts = 40 plots

Basic Results:
Crustaceans: reduced 58-96%
Algal biomass: increased 130-748%
Nutrients: inconsistent effects

Repeated Measures ANOVA

Effects Plot
Death By F-Table

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Graphical Illustration of ANOVA for Epiphyte Response

ANOVA's dirty secret: It's just a linear model with x = 0 or 1

ANCOVA with Macroalgae and Seagrass as Covariates

ANCOVA Results
Mediation in SEM

Gammarids class of crustations reduced by the pesticide.

Results show macroalgae predominantly promote gammarids while eelgrass predominantly promote epiphytes.

Results show macroalgae predominantly promote gammarids while eelgrass predominantly promote epiphytes.

Model fit leaves room for examining missing pathway.

Two Mediator Model

Do Caprellids explain remaining pesticide effect?

Final Model Results

Caprellids do explain remaining pesticide effect.

Macroalgae facilitate all amphipods and indirectly promote herbivory, protecting eelgrass.

Gammarids more precisely controlled by the pesticide.

Higher density of eelgrass associated with greater density of epiphytes.
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From ANOVAs to SEM

Our model results imply that behind this summary of mean responses is a network of effects like this.

Fit, Correlation, and Testing Models

Karl Pearson 1857-1936
Sir Ronald Fisher 1890-1962
Francis Galton 1822-1911

ANOVA
MLE

We can represent coefficients with line thickness…

pesticide epiphytes eelgrass
Caprellids Gammarids macroalgae

pesticide epiphytes eelgrass
Caprellids Gammarids macroalgae
Sewall Wright 1921 & 1st Gen SEM

A Parallel Tradition: Spearman & Factor Analysis in 1904

Jöreskog & 2nd Generation SEM

1. Model fit using covariance matrix of the data
2. Estimation of parameters via Maximum Likelihood
3. Can assess and compare fit of a multivariate model
Judea Pearl and 3rd Generation SEM

The networks of the mind represent our causal thinking about systems.

1. SEM with a graph theoretic framework
2. Causality is central
3. Methodological flexibility via piecewise approaches

Why hasn’t SEM received more attention in ecology?

eigenfactor.org

Path Analysis in Ecology: Ferrari 1963

Path Analysis and Food Webs

1) Coupling of observational data and causal manipulations
2) Evaluation of multiple hypotheses

Wootton, 1994 Ecology
Introduction Outline

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Storm Intensity and Frequency Increased over the Last 50 Years

East Pacific Winter Storm Intensity

North Pacific Winter Cyclone Frequency

Bromirski et al. 2003  Graham and Diaz 2001

Climate Change Prediction: The Largest Storm of the Year Will Get Stronger

IPCC AR 4

Winter cm NTR Wave Height

Bromirski et al. 2003
Testing Causality: Repeated Kelp Disturbance Experiment

- 4 Reefs selected in 2008 with paired 40x40m areas
- Giant Kelp removed in experimental plots every January to simulate disturbance

Effect of Kelp Removal on Richness Vary With Repeated Removals

Sampling of Rocky Reefs 2000-2009
Sampling of Rocky Reefs 2000-2009

- 40x2m transects
- Winter largest wave disturbance from CDIP
- Spring Kelp from LANDSAT
- Quadrat, swath, and point counts for giant kelp & 250 other conspicuous algae, fish, and invertebrates
- Feeding links derived from peer reviewed literature, CDFG reports, dissertations, and expert knowledge

Quantifying Food Web Structure

Herbivores

- Species Richness
- by functional group

Algae

- Linkage Density
- etc...

Direct and Indirect Effects of Waves on Food Webs: Simple, Right?

Food Web Diversity And Structure

Kelp

Wave Disturbance

Things Get More Complex...

Food Web Diversity And Structure

Summer Kelp

Spring Kelp

Winter Wave Disturbance
The Full Model

Food Web Diversity
And Structure

Summer Kelp

Winter Wave Disturbance
Wave*Kelp Interaction
Last Year’s Kelp

Wave Disturbance Indirectly Related to Food Web Structure

4) More species = more feeding links per species
3) Kelp density increases richness, but spring canopy decreases richness
2) More kelp in the spring = more kelp in the summer
1) Big waves remove kelp (where there is kelp)

Effect of Waves Differs for Algae v. Animals

1) Waves DECREASE sessile invert and mobile species richness via kelp removal
2) Waves INCREASE algal richness by altering light availability
3) Increase in algal richness due to waves outweighs decrease in animal richness

Last Year’s Kelp Influences This Year’s Food Web Structure

Byrnes et al. 2011 Global Change Biology

Byrnes et al. 2011 Global Change Biology
SEM and Simulations

Food Web Diversity And Structure

- Winter Wave Disturbance
- Wave*Kelp Interaction
- Last Year’s Kelp
- Spring Kelp
- Summer Kelp

Spring Kelp = Waves + Last Year’s Kelp + Waves*Last Year’s Kelp
Summer Kelp = Waves + Last Year’s Kelp + Spring Kelp
Richness = Waves + Last Year’s Kelp + Spring Kelp + Summer Kelp
Etc.....

Climate Change May Simplify Kelp Forest Food Webs

1. Free resources from wave disturbance may initially promote diversity and complexity

2. Loss of foundation species leads to simplified food webs

QUESTIONS & COFFEE