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 – Advanced Topics & Open Lab

S – Project Presentations

Typical Day

9:00 – 10:30 Lecture/Lab I

10:30 – 10:45 Break!

10:45 – 12:00 Lecture/Lab II

12:00 – 1:00 Lunch

1:00 – 2:30 Lecture/Lab III

2:30 – 3:00 Break!

3:00 – 4:30 Lecture

4:30 – 5:30 Work with Your Data

Where You can Learn More about SEM


also, see www.structuralequations.org

Software for SEM

1. R with lavaan, piecewiseSEM, 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!
Who am I?

Who are you? Why are you here?

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

The Scientific Enterprise is Influenced by our Statistical Methodology

**SEM is a form of Graphical Modeling**

Equation form: \[ y_1 = \gamma_{11}x_1 + \zeta_1 \]

Graphical form: 

**The Structure in SEM implies CAUSALITY**

Equation form: \[ y_1 = \gamma_{11}x_1 + \zeta_1 \]

Graphical form without causality: 

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

Hypothesis involving indirect effects:

Corresponding Equations:

\[ y_1 = \gamma_{11}x_1 + \zeta_1 \]
\[ y_2 = \beta_{21}y_1 + \gamma_{21}x_1 + \zeta_2 \]
\[ y_3 = \beta_{31}y_2 + \gamma_{31}x_1 + \zeta_3 \]

**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

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Fit, Correlation, and Testing Models

Karl Pearson 1857-1936

Sir Ronald Fisher 1890-1962

Francis Galton 1822-1911

ANOVA

MLE
The First Path Diagram?

- Wright 1920 PNAS

A Parallel Tradition: Spearman & Factor Analysis in 1904

- General Intelligence: Objectively Determined and Measured

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

Jöreskog & 2nd Generation SEM

- Sewall Wright 1921 & 1st Gen SEM

- Jöreskog & 2nd Generation SEM

- Factor Analysis in 1904

- Mechanical

- Verbal

- Spatial

- Numerical
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
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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. Whalen\(^1\), J. Emmett Duffy\(^1\), James B. Grace\(^2\)
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:
- 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
Graphical Illustration of ANOVA for Epiphyte Response

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

ANOVA Results

ANCOVA with Macroalgae and Seagrass as Covariates

Mediation in SEM

Gammarids class of crustations reduced by the pesticide.
Mediation in SEM

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

Two Mediator Model

Do Caprellids explain remaining pesticide effect?

Final Model Results

Caprellids do explain remaining pesticide effect.

We can represent coefficients with line thickness...

Gammarids more precisely controlled by the pesticide.

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

Higher density of eelgrass associated with greater density of epiphytes.
Our model results imply that behind this summary of mean responses... is a network of effects like this.

**From ANOVAs to SEM**

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

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Storm Intensity and Frequency Increased over the Last 50 Years

East Pacific Winter Storm Intensity

North Pacific Winter Cyclone Frequency

Graham and Diaz 2001

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

IPCC AR 4

Bromirski et al. 2003

IPCC AR 4
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

- Species Richness - by functional group
- 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
- Spring Kelp

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

Wave Disturbance Indirectly Related to Food Web Structure

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

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
**SEM and Simulations**

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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....
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**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**