

What is Structural Equation Modeling?

Jim Grace



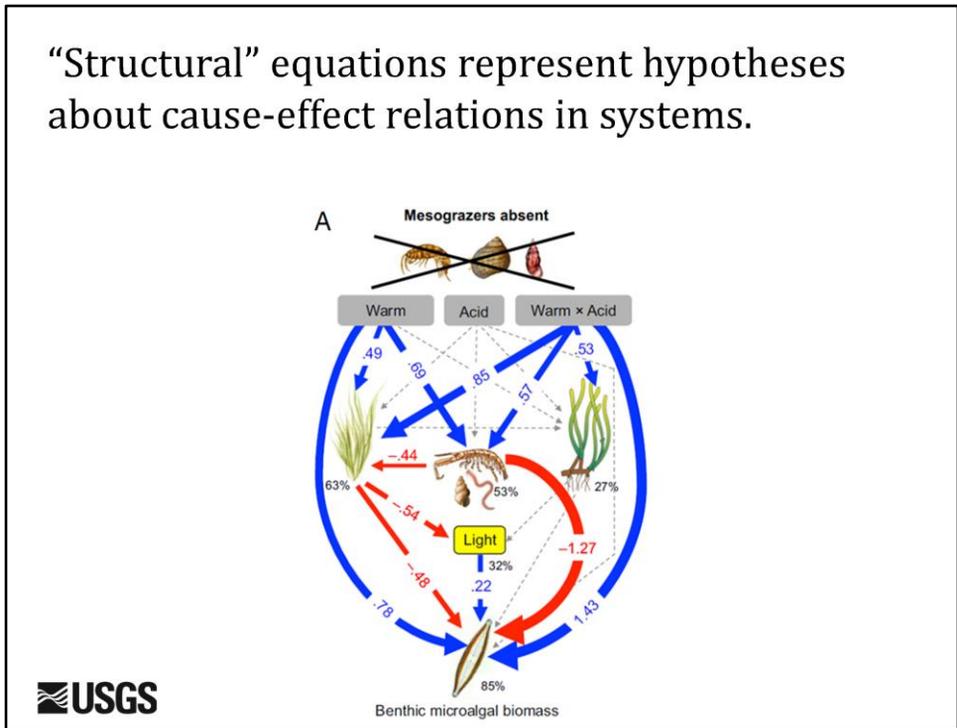
U.S. Department of the Interior
U.S. Geological Survey

1. What is “Structural Equation Modeling?” Here I try to provide a general answer to that question.

(A recent citation for the material summarized in this tutorial is:
Grace, J.B., Schoolmaster, D.R. Jr., Guntenspergen, G.R., Little, A.M.,
Mitchell, B.R., Miller, K.M., and Schweiger, E.W. 2012. Guidelines for
a graph-theoretic implementation of structural equation modeling.
Ecosphere 3(8): article 73 (44 pages).
<http://www.esajournals.org/doi/pdf/10.1890/ES12-00048.1>)

Notes: IP-061819; Support provided by the USGS Climate & Land
Use R&D and Ecosystems Programs. I would like to acknowledge
formal review of this material by Lauren Pile, Clemson University and
Diane Larson, USGS. Many helpful informal comments have
contributed to the final version of this presentation. The use of trade
names is for descriptive purposes only and does not imply endorsement
by the U.S. Government. Questions about this material can be sent to
sem@usgs.gov.
Last revised 15.04.09.

“Structural” equations represent hypotheses about cause-effect relations in systems.



1. Regarding the meaning of the word “structural”, structural equations are those that aspire to represent cause-effect relationships. A key feature of structural equation models is the ability to investigate the networks of connections among system components.
2. We can contrast structural equations with descriptive equations. Most statistical models do not attempt to represent cause-effect connections, but only estimates of association. SEM differs in its aspiration by trying to represent scientific, causal hypotheses.
3. Here I show a graphical representation of a model published by Alsterberg et al. that quantifies what happens in an oceanic system when mesograzers are removed at the same time that warming and acidification are applied. Represented in this figure is the experimental removal of mesograzers along with the standardized positive effects in blue and negative effects in red.

(Illustration in the slide represents work reported in:
 Alsterberg, C., Eklof, J.S., Gamfeldt, L., Havenhand, J.N., and Sundback, K. 2013. Consumers mediate the effects of experimental ocean acidification and warming on primary producers. PNAS)

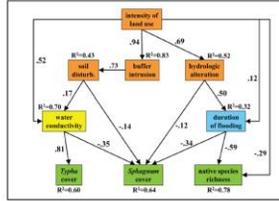
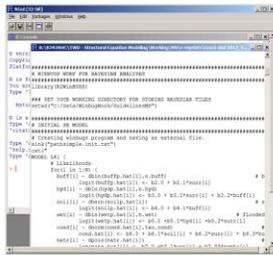
Structural equation modeling (SEM) can be described in a number of ways, e.g., as a

- (1) scientific framework
- (2) means of testing theoretical ideas
- (3) workflow process
- (4) method of learning
- (5) means of modeling networks
- (6) body of knowledge
- (7) tradition shaped by history
- (8) community of practice



1. Structural equation modeling, or “SEM” can be thought of in a number of ways; for example, as a
 1. scientific framework
 2. means of testing theories
 3. workflow process
 4. method of learning
 5. means of modeling networks
 6. body of knowledge
 7. tradition shaped by history, and
 8. community of practice
2. In the next set of slides I will say a little about each one of these viewpoints.

(1) SEM is a scientific framework for evaluating hypotheses about causal connections in systems.



Statistical & causal analysis methods,

applied using the SEM framework,

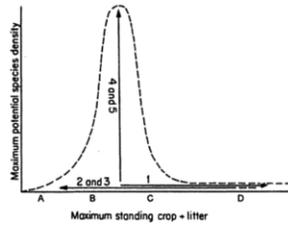
are used to evaluate causal hypotheses about systems.



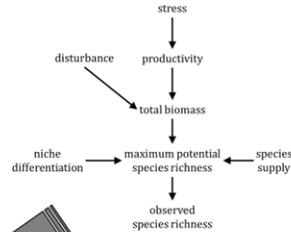
1. SEM is a modeling framework for scientific hypotheses.
2. The graphic here is meant to make the point that we use statistical and causal analysis methods within the SEM framework to seek a causal understanding about the multiple processes operating in systems. There are actually two complementary points of emphasis in SEM - evaluating causal hypotheses and investigating systems.

(2) SEM is a way of translating scientific ideas into a testable form.

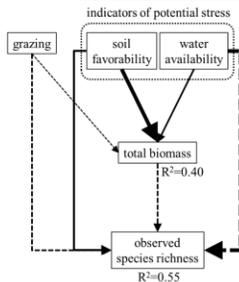
Theoretical Idea



Causal Diagram



SEM Results



SEM can be used to evaluate the causal diagram and, thus, the theory.



1. SEM also provides us with a means for translating abstract ideas into testable expectations.
2. Here we show a qualitative theoretical idea on the left. In the right-hand figure, a causal diagram is presented that represents the translation of ideas associated with the theoretical idea into the form of a network of relations. Using the causal diagram and data, we can arrive at a new and quantitative understanding.

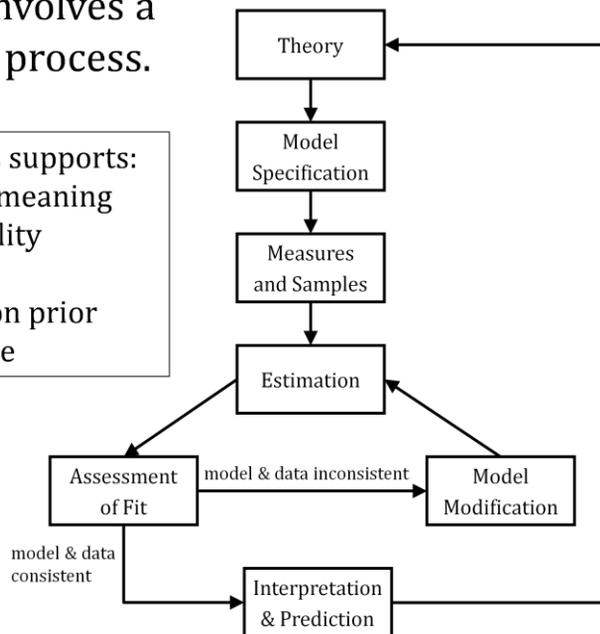
(Inset figure is an excerpt from: Grime, J.P. (1979) *Plant Strategies, Vegetation Processes and Ecosystem Properties* (1st ed.). Chichester: Wiley. Publ.

Word and arrow causal diagram (right side of slide) from:
 Grace, J.B., Adler, P.B., Harpole, W.S., Borer, E.T., and Seabloom, E.W. 2014 Causal networks clarify productivity–richness interrelations, bivariate plots do not. *Functional Ecology*, 28:787-798.
 (<http://onlinelibrary.wiley.com/doi/10.1111/1365-2435.12269/abstract>)

(3) SEM involves a workflow process.

This process supports:

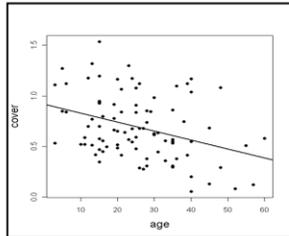
- clarity of meaning
- repeatability
- learning
- building on prior knowledge



1. SEM is a scientific process. It relies on sequential learning and a general multi-step process to build confident knowledge.
2. Individual studies are ALWAYS limited in the degree of confidence we should place on them.
3. In SEM, we first translate our ideas into models, test those models, modify our models if need be, and then use that knowledge to inform where we start with the next study.

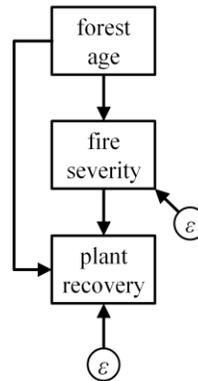
(4) SEM is a method of learning.

Starting with an Observation



We learn about mechanisms by testing our explanations.

Investigate Causes behind Observation

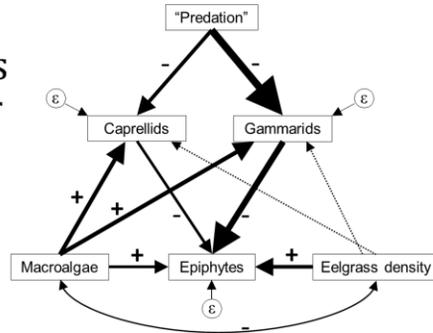


1. SEM is also a method for learning. This example shows data on the effects of wildfire on southern California ecosystems.
2. Here, we start with the observation that there is a relationship between post-fire plant recovery.
3. We can propose and test ideas about the processes behind the observation using SEM. In this case, we evaluate the idea that fire severity might explain all or part of the relationship between forest age and plant recovery
4. Through the use of this kind of test, we can dig deeper and deeper into understanding systems by bringing in more variables.
5. A hugely important side benefit is the ability to detect and discover new processes that we may not have even suspected as being important.

(5) SEM is a quantitative methodology with a characteristic equational form for modeling networks of relationships.

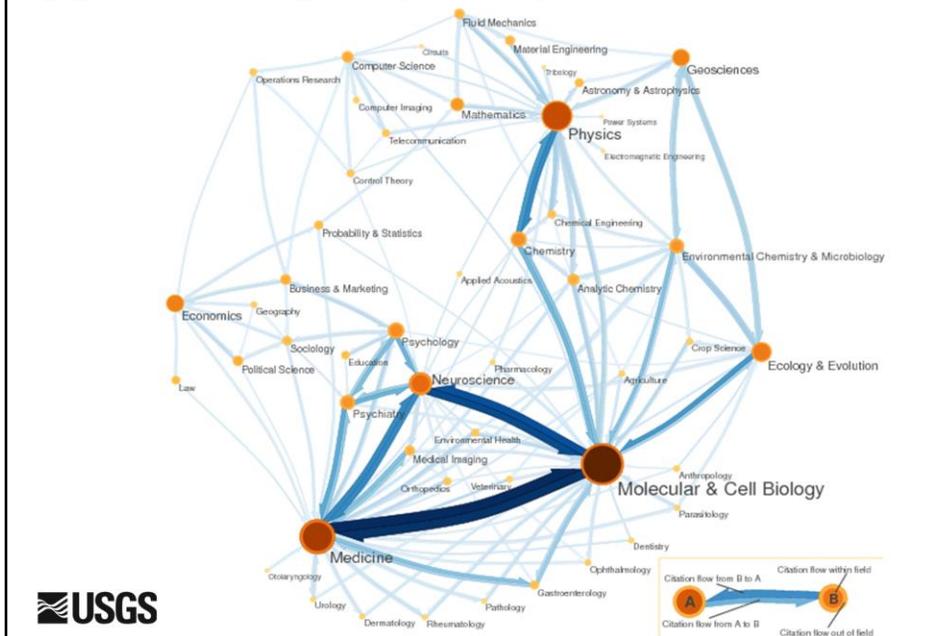
$$Y = f(X, Y)$$

y s as functions of other y s permits representation of networks.



1. Structural equation models also have a particular form.
2. In these models, responses (y-variables) can depend on other responses (other y-variables), allowing networks of relationships to be represented.
3. Classic linear additive relations, as in the first equation, can of course be generalized to include a wide variety of specification forms.

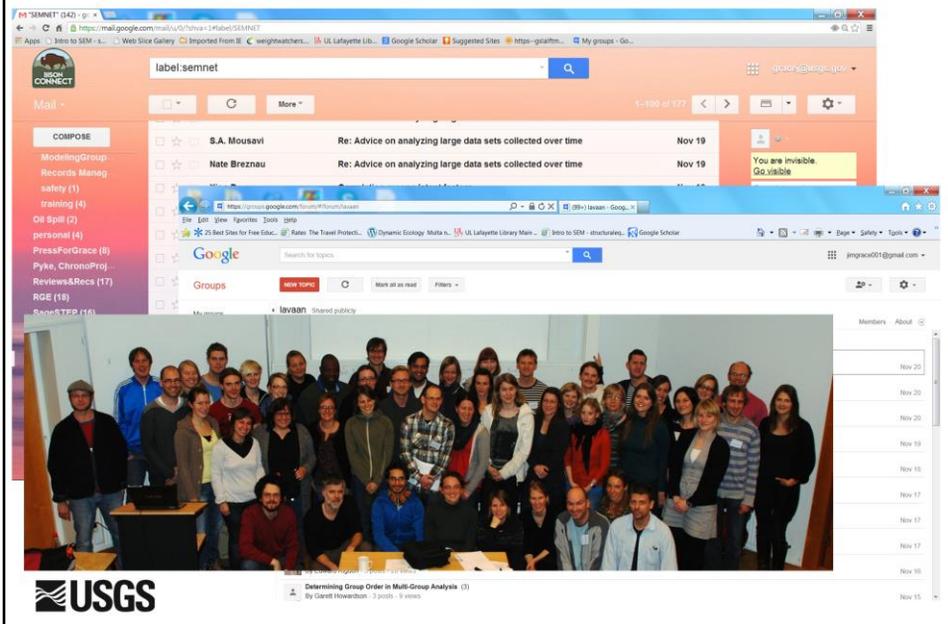
(7) SEM is shaped by history.



1. History has played a role in shaping the literature on SEM.
2. This diagram represents a citation map showing the historical flow of knowledge among disciplines.
3. It is important to realize how the flow of information, and especially the lack of flow of information, shapes peoples' perceptions of quantitative methods.
4. Understanding the influence of history helps us to realize how many important bodies of knowledge, such as that related to SEM, are relevant to our science even if not currently part of the common body of practice.

map from (<http://www.eigenfactor.org/map/maps.htm>)

(8) SEM is a community of practice.



1. SEM is also a community of practice. There are active online discussion groups, both general and specifically related to software packages, as well as working groups focused on particular scientific problems.
2. The fact that SEM requires both scientific and statistical training means SEM instructors are nearly always cross-trained individuals – scientists with quantitative backgrounds.

More information available at
<http://www.nwrc.usgs.gov/SEM/index.html>

Also,
you can search “structural equation modeling”
plus your subject of interest.



I hope this overview has been useful. For more information, go to our webpage or search for examples involving your subject of interest.