1. A Brief History of SEM

Overview

1. What is SEM?
2. A History Lesson
3. From ANOVA to SEM

1.1 What is SEM?

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Structural Equation Modeling

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Structural Equation Modeling

There is hypothesized underlying *structure* to nature…

1.1 What is SEM?

Structural

There is hypothesized underlying *structure* to nature…

Equation

…that can be translated to a series of mathematical *equations*…

Modeling

1.1 What is SEM?

Structural

There is hypothesized underlying *structure* to nature…

Equation

…that can be translated to a series of mathematical *equations*…

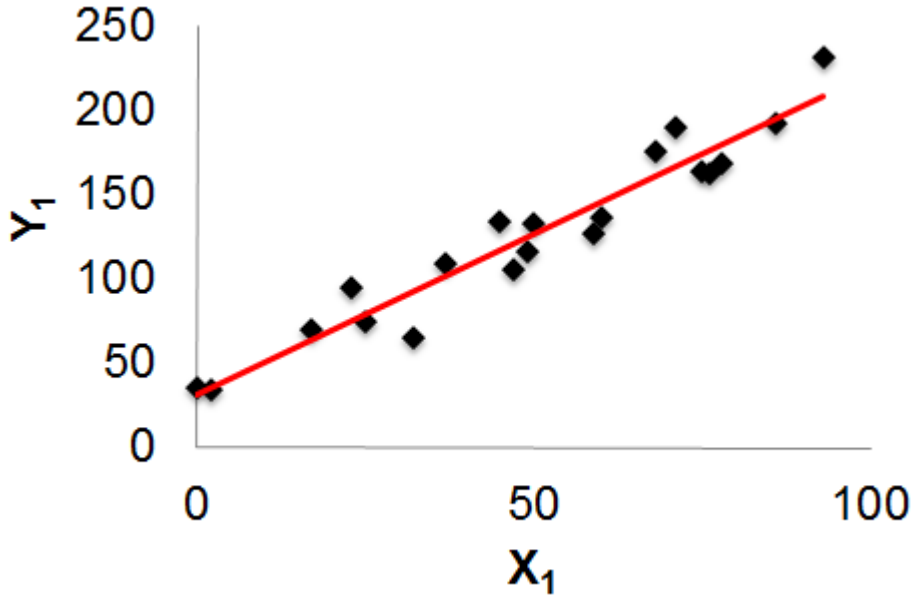
Modeling

…which can be *modeled* against data to support or refute the proposed structure

1.1 What is SEM? By any other name …

- Structural equation modelling (SEM)
- (Confirmatory) path analysis
- Directed acyclic graph model

1.1 What is SEM? A graphical approach

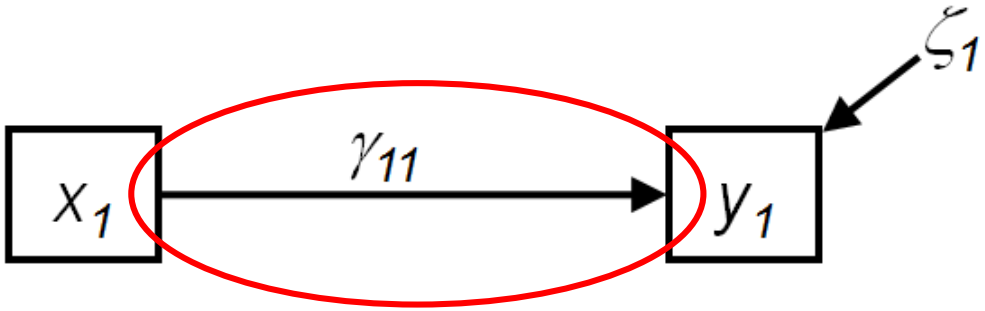


Equation form

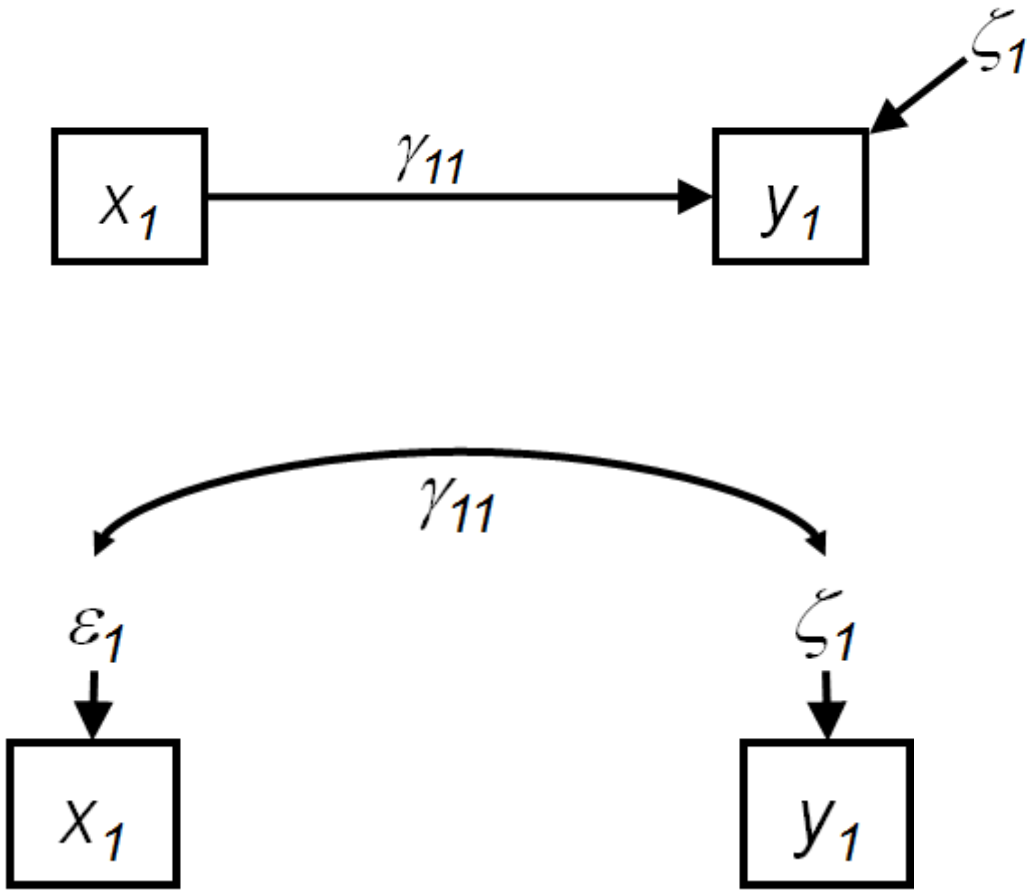
$$y_1 \sim \alpha_1 + \beta_1 X_1 + \varepsilon$$

$$y_{11} \sim \alpha_1 + \gamma_{11} x_1 + \zeta_1$$

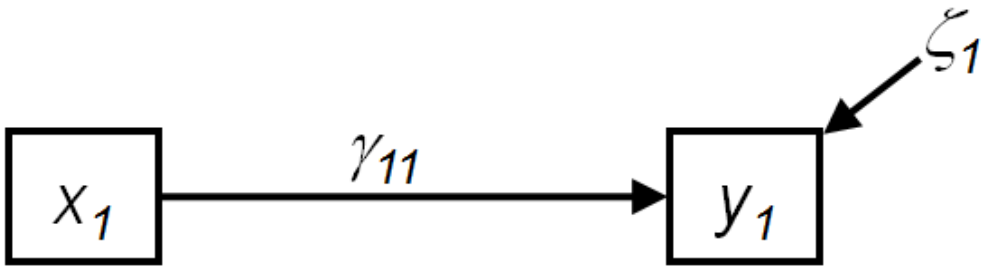
Graphical form



1.1 What is SEM? Directionality

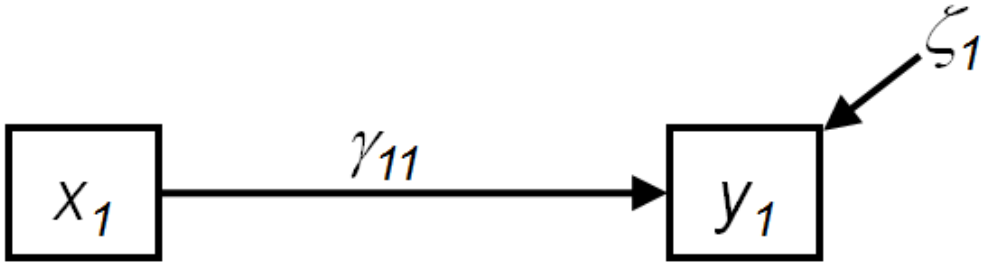


1.1 What is SEM? The elephant in the room



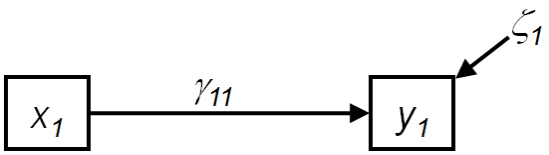
"An equation…can be said to be *structural* if there exists sufficient evidence from all available sources to support the interpretation that x_1 has a causal effect on y_1." (Grace, 2006)

1.1 What is SEM? What is *causation*?

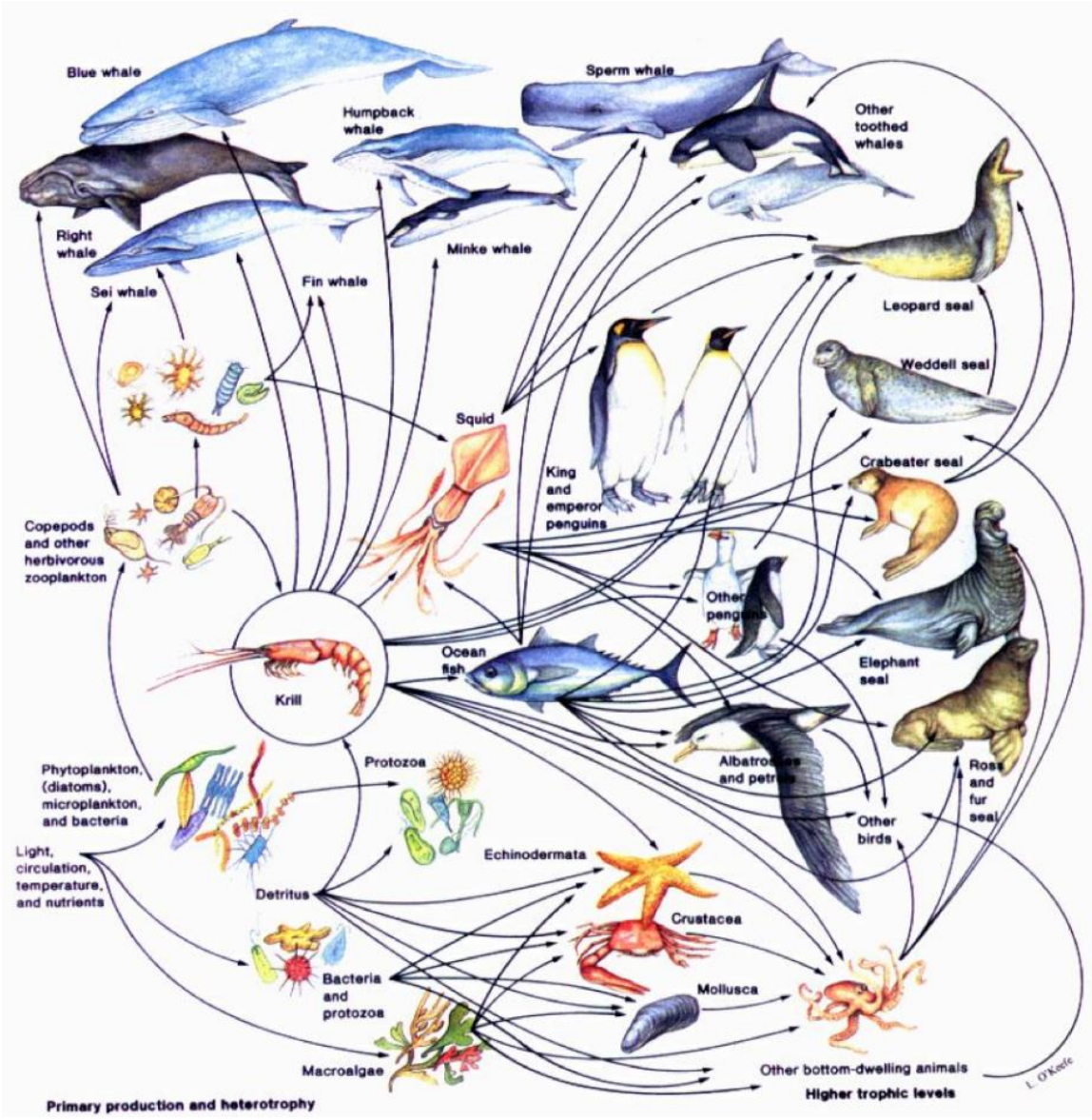


- **Key Point #1:** SEM assumes that *x* causes *y*
  - Prior observation (a hunch)
  - Prior statistical models
  - Prior experimentation
  - Some or all of the above
- Does not assume ultimate causation

1.1 What is SEM? Nature is complex

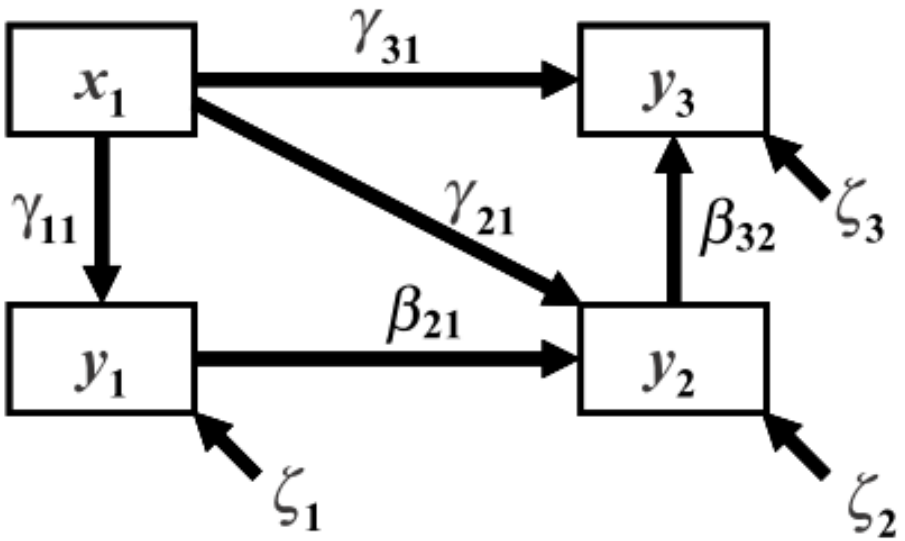


vs.



1.1 What is SEM? Incorporating complexity

Graphical model



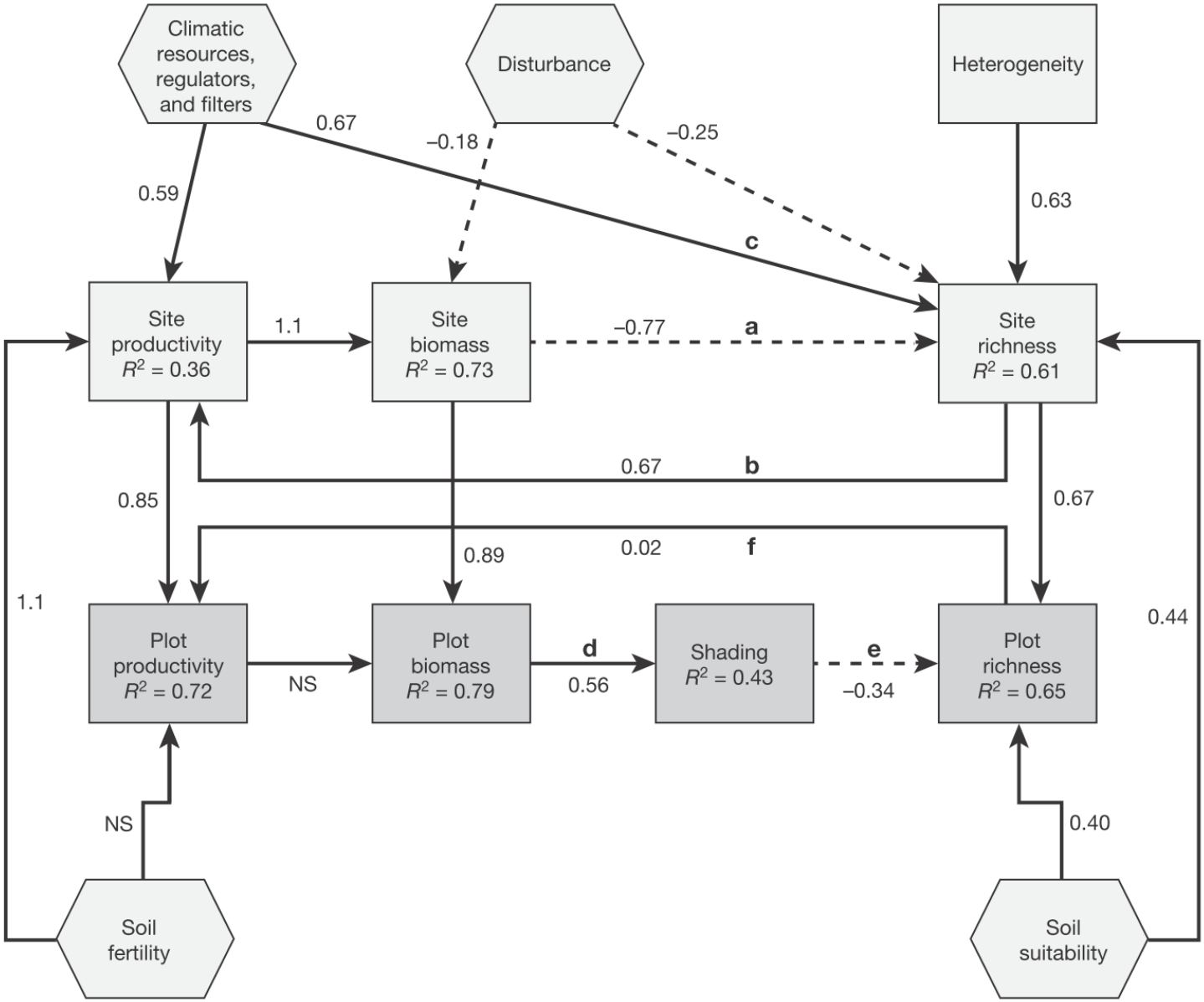
List of equations

$$y_1 = \alpha_1 + \gamma_{11} x_1 + \zeta_1$$

$$y_2 = \alpha_2 + \beta_{21} y_1 + \gamma_{21} x_1 + \zeta_2$$

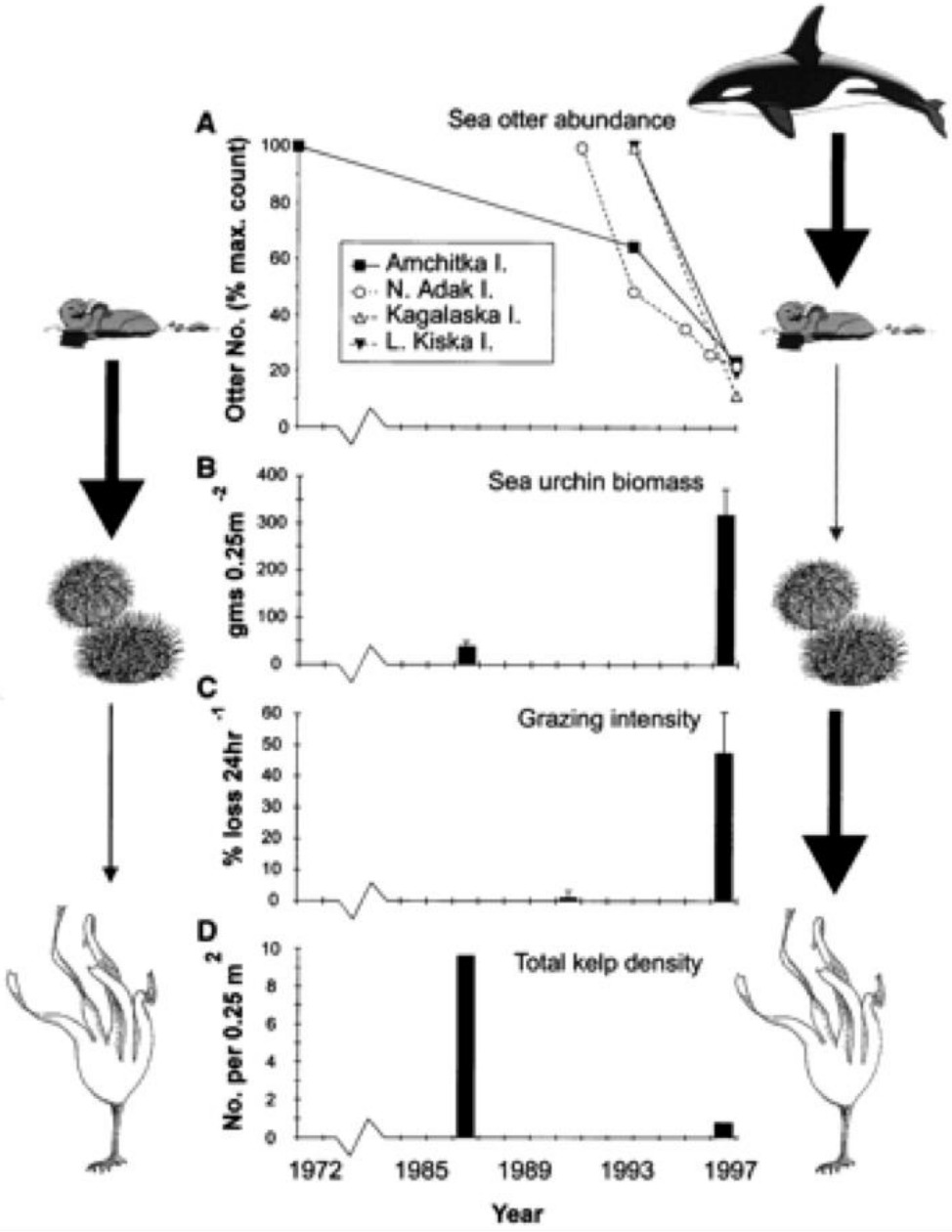
$$y_3 = \alpha_3 + \beta_{32} y_2 + \gamma_{31} x_1 + \zeta_3$$

1.1 What is SEM? Building up

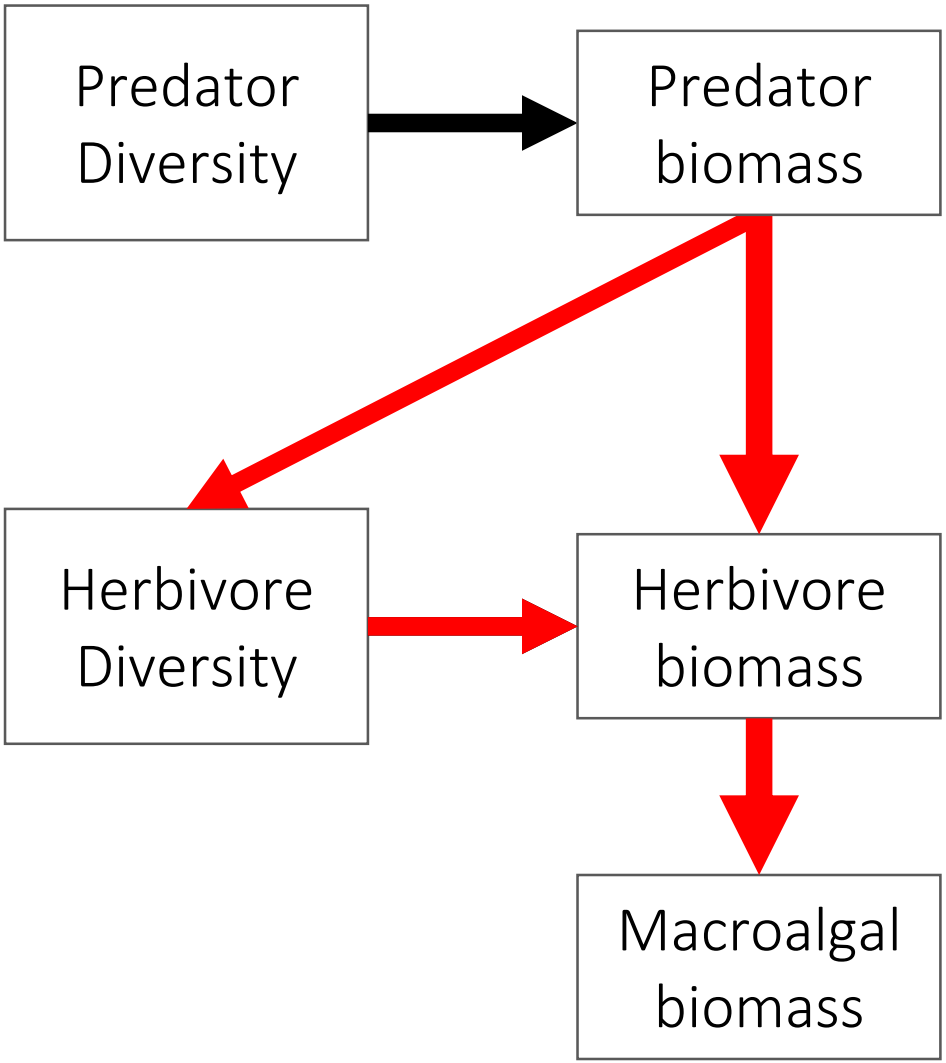


1.1 What is SEM? A complicated network

- **Key Point #2:** By combining inferences across multiple equations, SEM addresses both direct and indirect effects in a system



1.1 What is SEM? Indirect effects



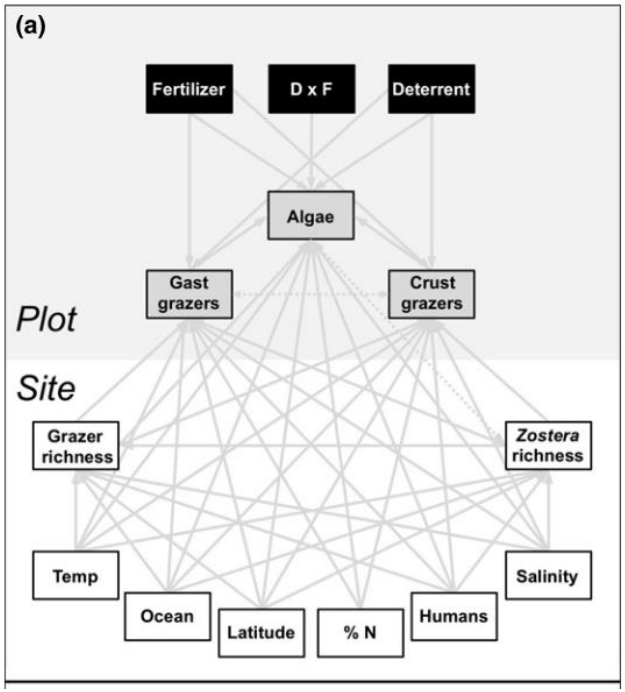
1.1 What is SEM? Putting it all together

- **Key Point #1:** SEM assumes that *x* causes *y*

- **Key Point #2:** By combining inferences across multiple equations, SEM addresses both direct (proximate) and indirect (ultimate) effects in a system

1.1 What is SEM? Reality vs. model

Model



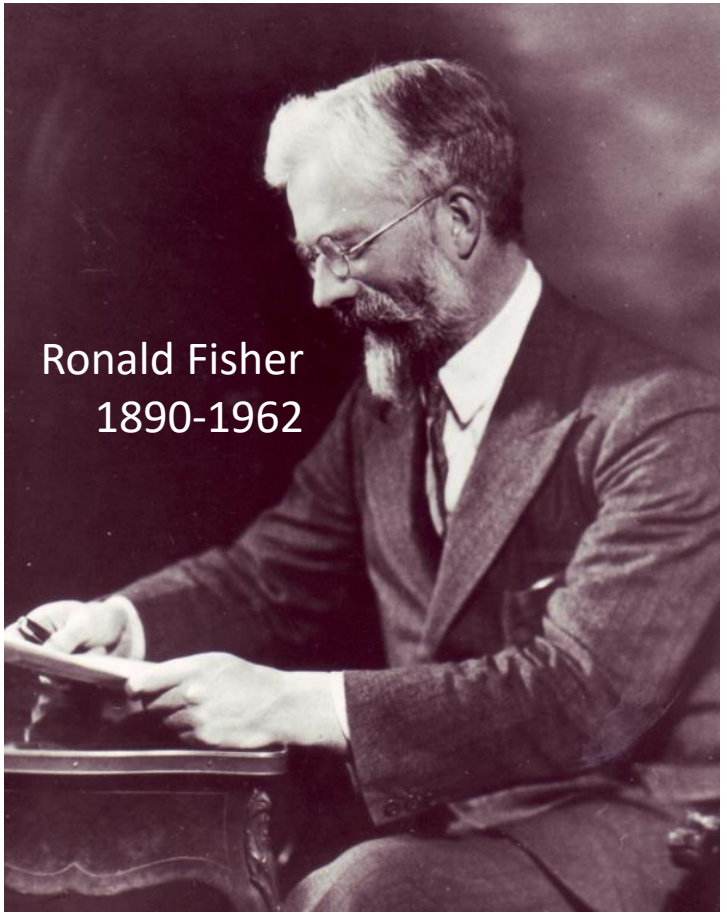
Real world

Real world informs the model, not the other way around!

1.2 A History Lesson

1.2 History. Time warp

Pearson product moment correlation, *r*
Chi-squared goodness of fit, χ^2



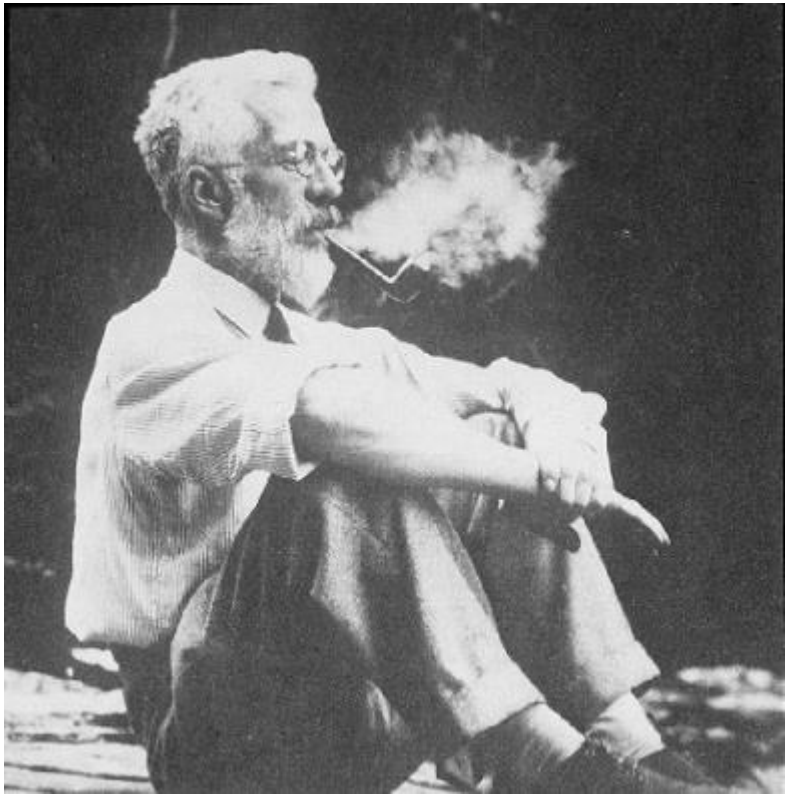
ANOVA
Maximum likelihood estimation

1.2 History. Causation vs. correlation

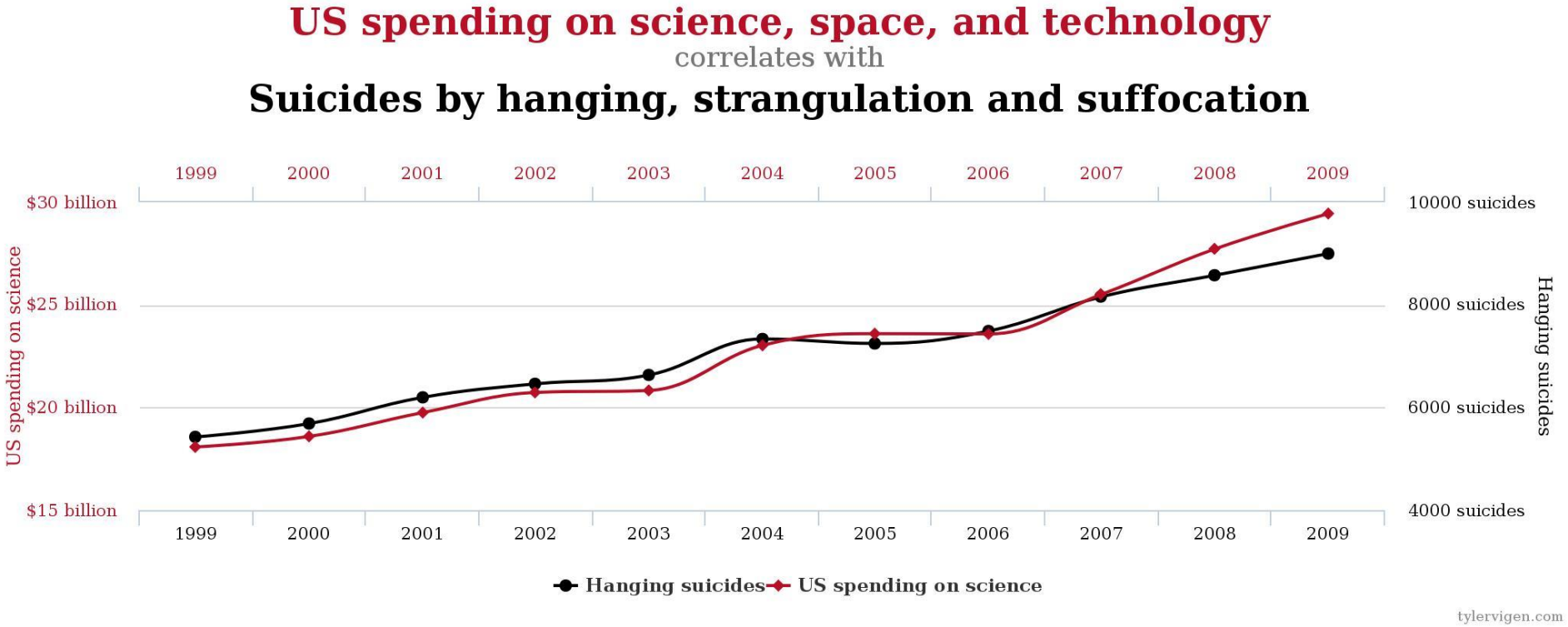
Smoking → Cancer

Cancer → Smoking

Smoking ← Gene → Cancer

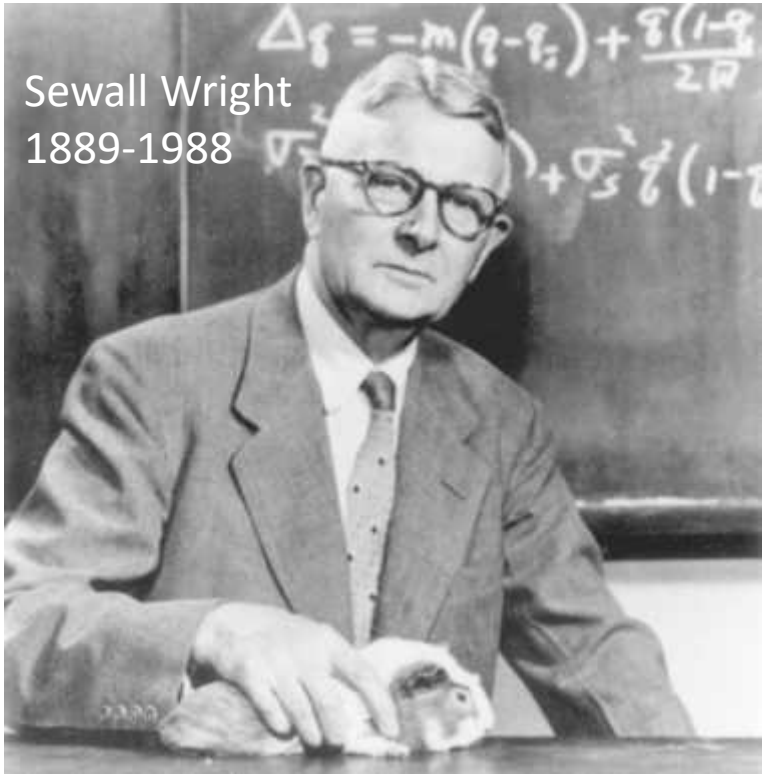


1.2 History. Causation vs. correlation

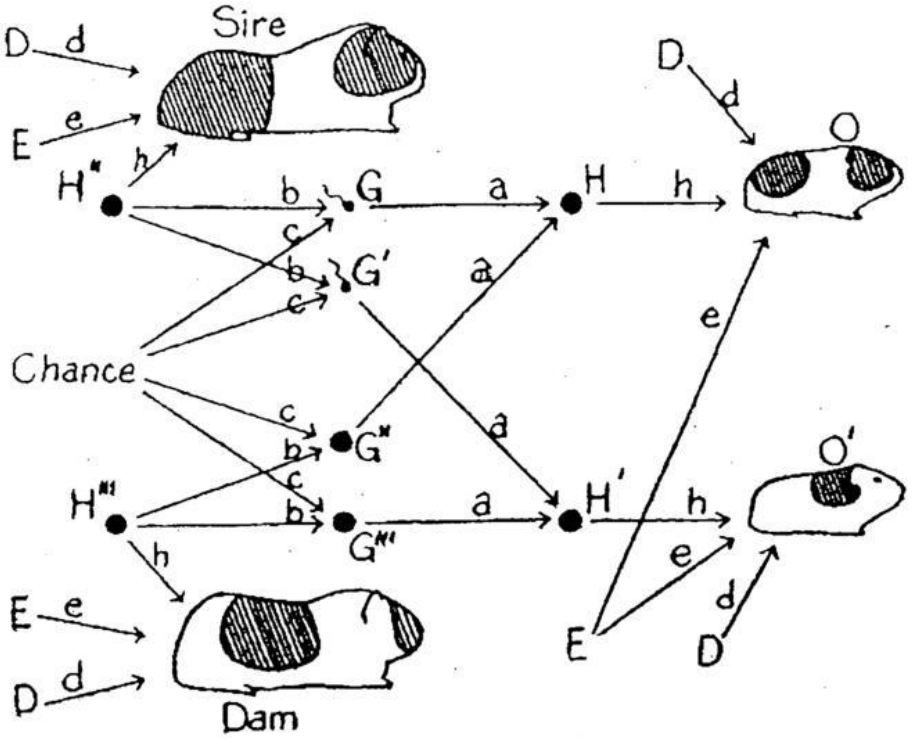


http://www.tylervigen.com/

1.2 History. Causation vs. correlation



Path analysis



1.2 History. Causation vs. correlation

"The basic fallacy of the method appears to be the assumption that it is possible to set up *a priori* a comparatively simple graphic system which will truly represent the lines of action of several variables upon each other, and upon a common result. . . . The pure mathematics by which this is shown is apparently faultless in the sense of algebraic manipulation, but it is based upon assumptions which are wholly without warrant from the standpoint of concrete, phenomenal actuality." (Niles, 1922)

"The writer has never made the preposterous claim that the theory of path coefficients provides a general formula for the deduction of causal relations. He wishes to submit that the *combination* of knowledge of correlations with knowledge of causal relations, to obtain certain results, is a different thing from the *deduction* of causal relations from correlations implied by Niles's statement. Prior knowledge of the causal relations is assumed as a prerequisite in the former case. Whether such knowledge is ever possible seems to be the subject of Niles's philosophical discussion of the nature of causation." (Wright, 1923)

1.2 History. Causation vs. correlation

"The basic fallacy of the method appears to be the assumption that it is possible to set up *a priori* a comparatively simple graphic system which will truly represent the lines of action of several variables upon each other, and upon a common result. . . . The pure mathematics by which this is shown is apparently faultless in the sense of algebraic manipulation, but it is based upon assumptions which are wholly without warrant from the standpoint of concrete, phenomenal actuality." (Niles, 1922)

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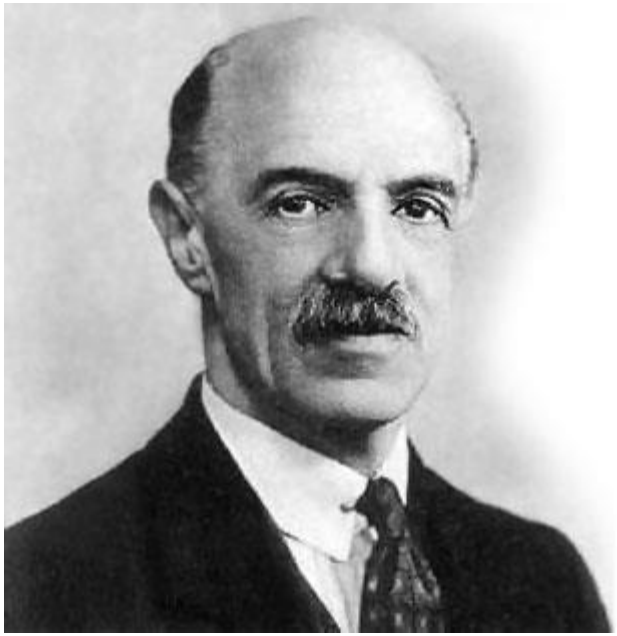
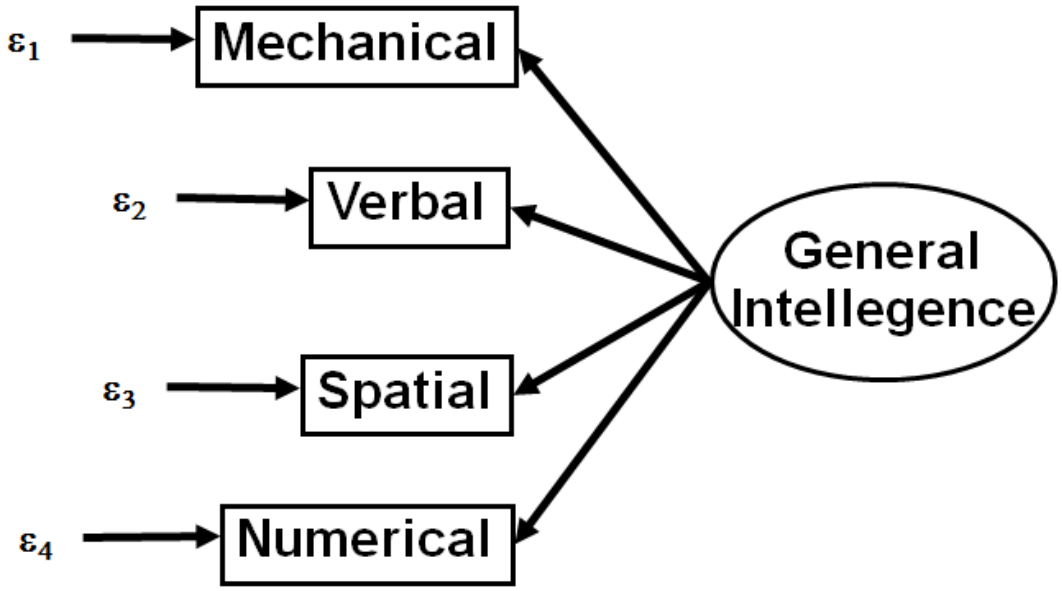
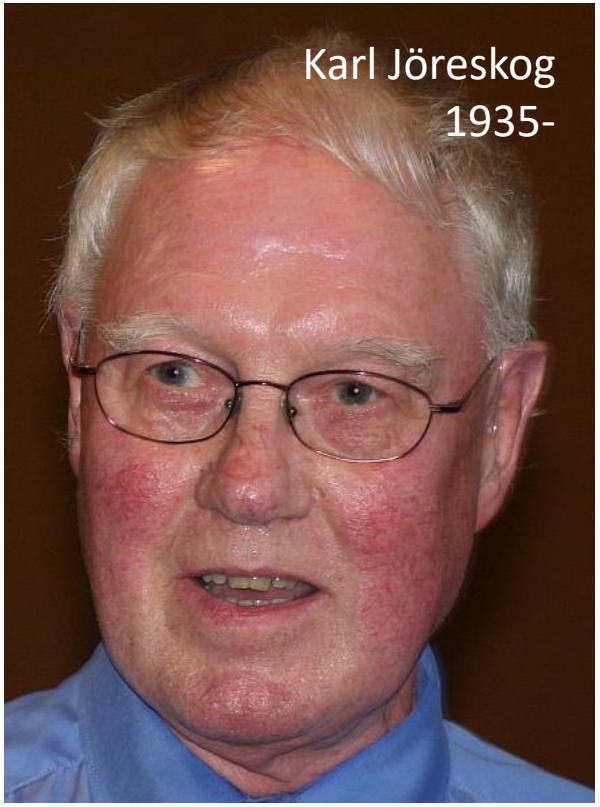
1.2 History. Factor Analysis

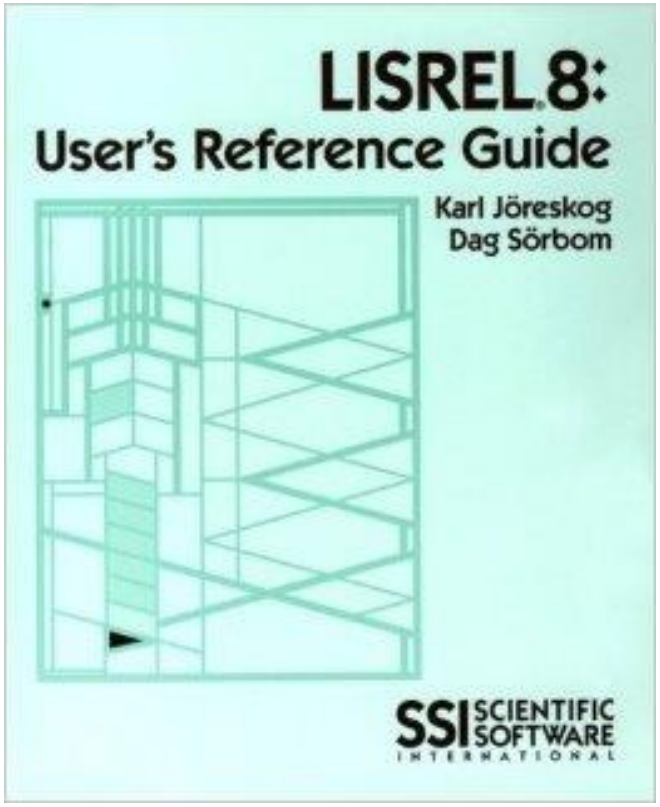


Charles Spearman
1863-1945



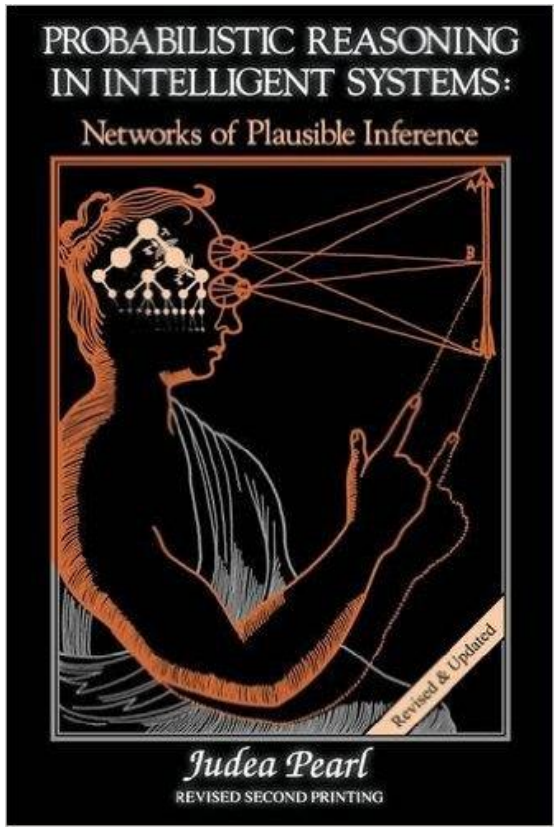
1.2 History. 2nd Generation SEM





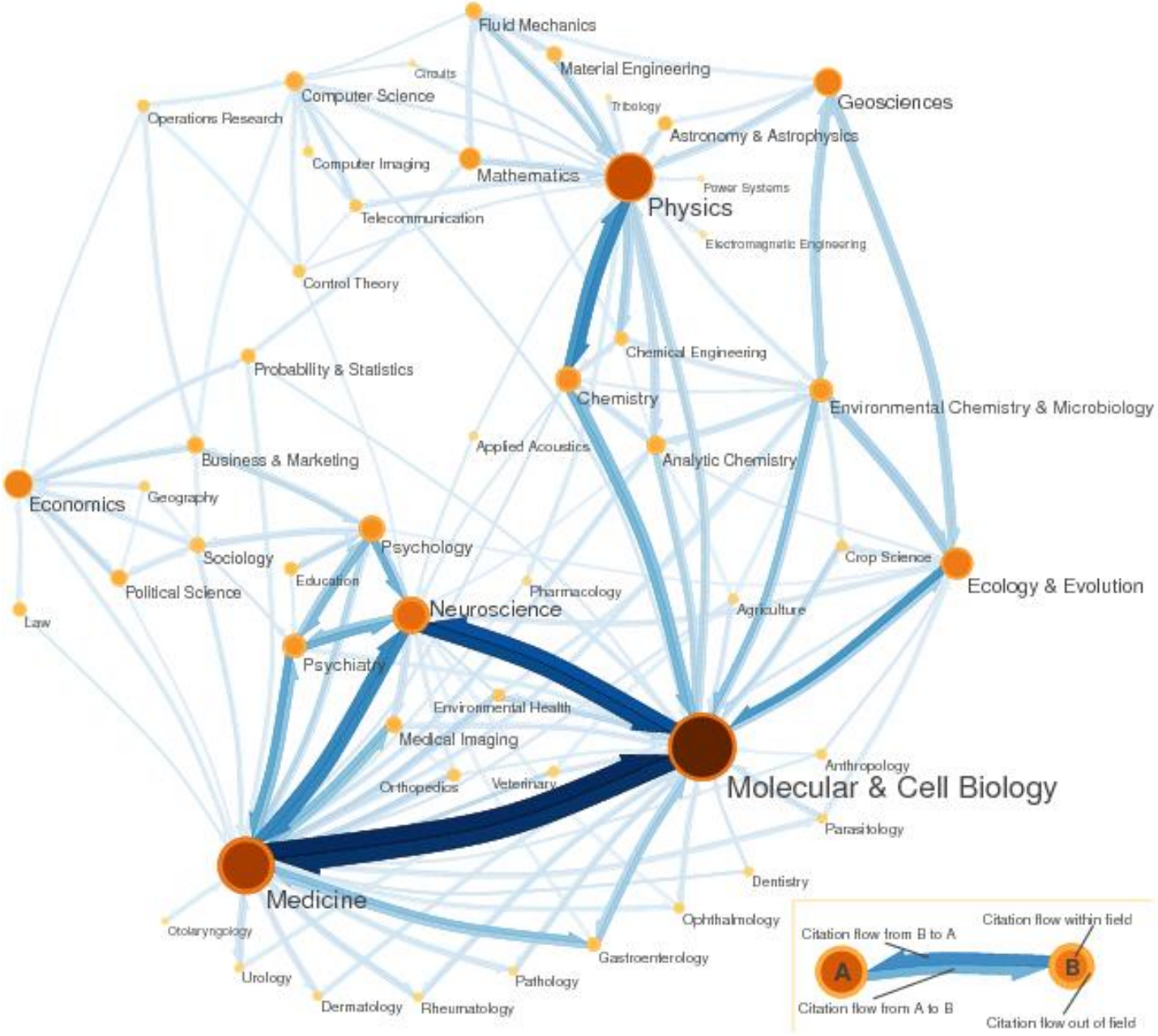
- LISREL = combine path and factor analysis
- Model fit using covariance and ML estimation
- Assess and compare fit of multivariate model

1.2 History. 3rd Generation SEM

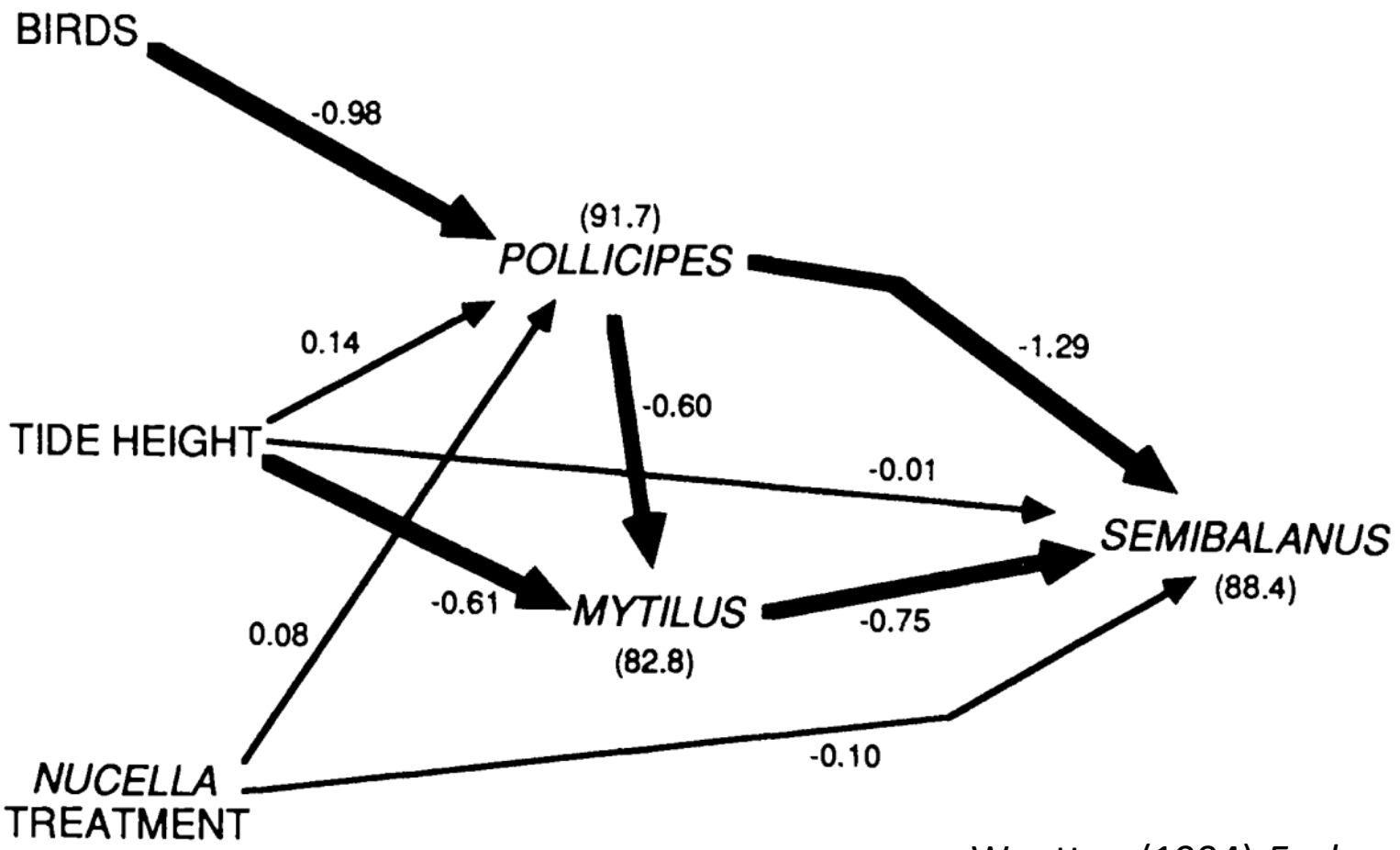


- Unite SEM with graph theory
- Causality is central
- Flexible methods with piecewise approach

1.2 History. SEM and Ecology

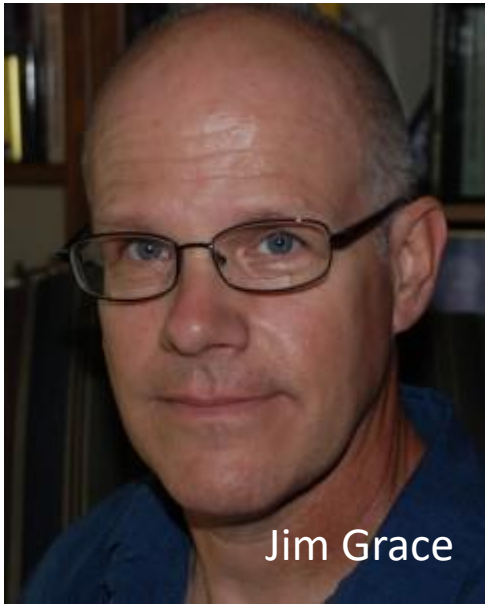


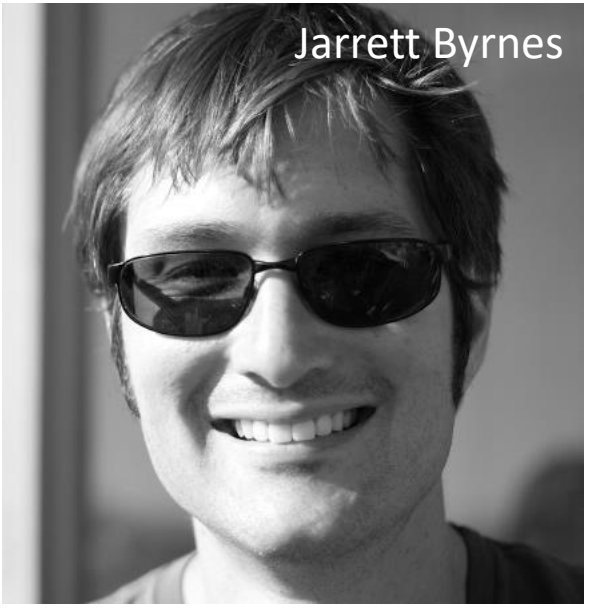
1.2 History. SEM and Ecology

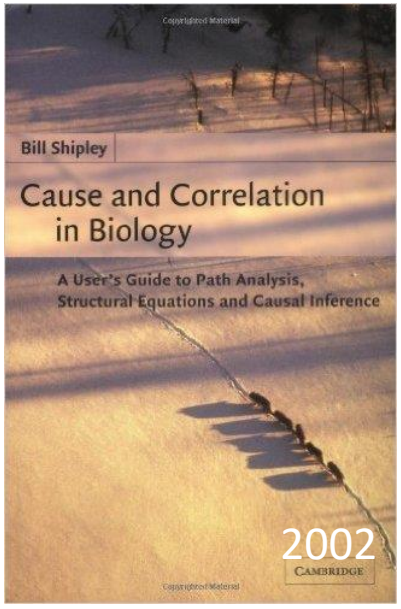


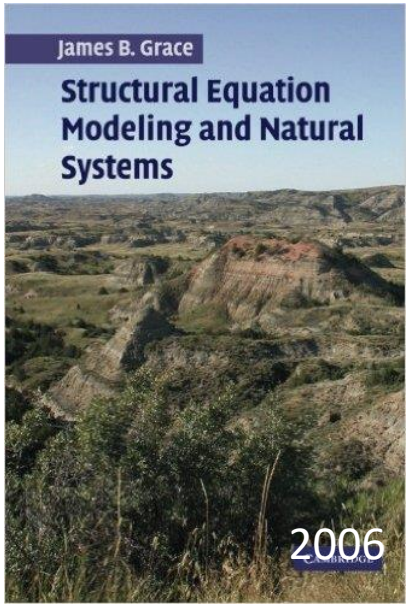
Wootton (1994) *Ecology*

1.2 History. SEM and Ecology









1.3 From ANOVA to SEM

1.3 From ANOVA to SEM. Whalen et al. 2013

Ecology, 94(2), 2013, pp. 510–520
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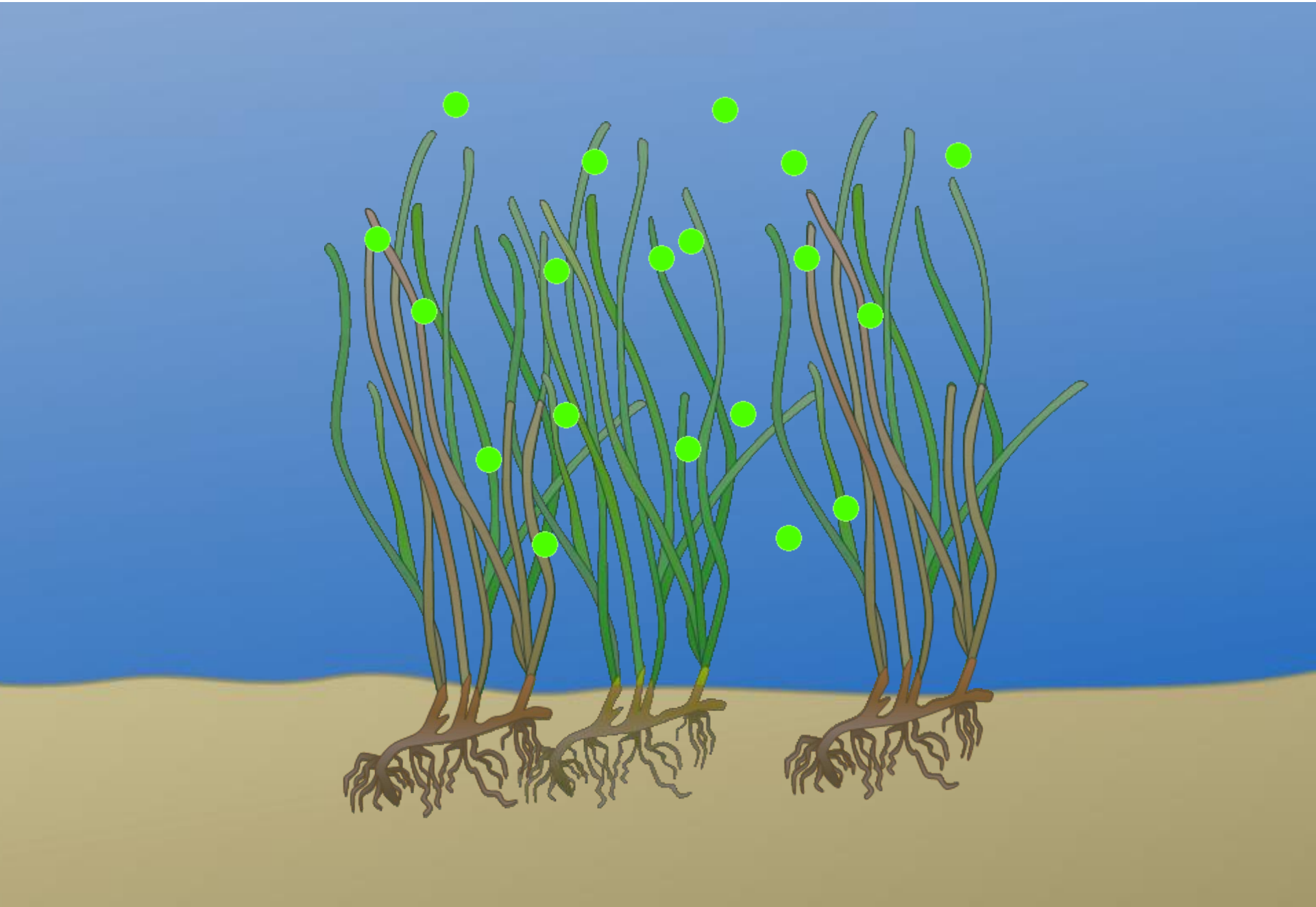
Temporal shifts in top-down vs. bottom-up control of epiphytic algae in a seagrass ecosystem

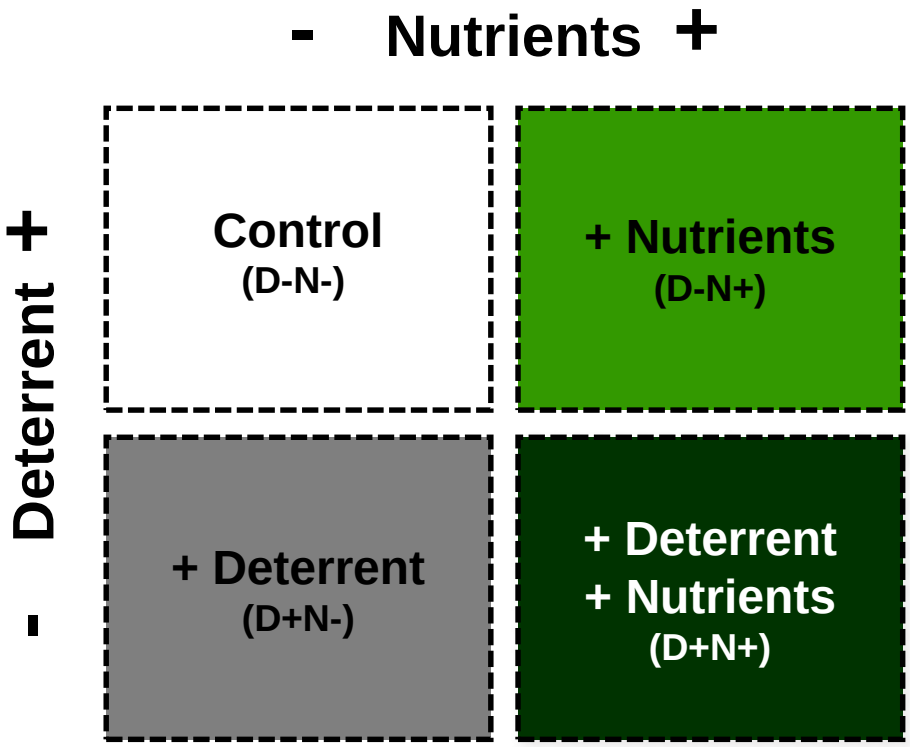
MATTHEW A. WHALEN,[1,3] J. EMMETT DUFFY,[1] AND JAMES B. GRACE[2]

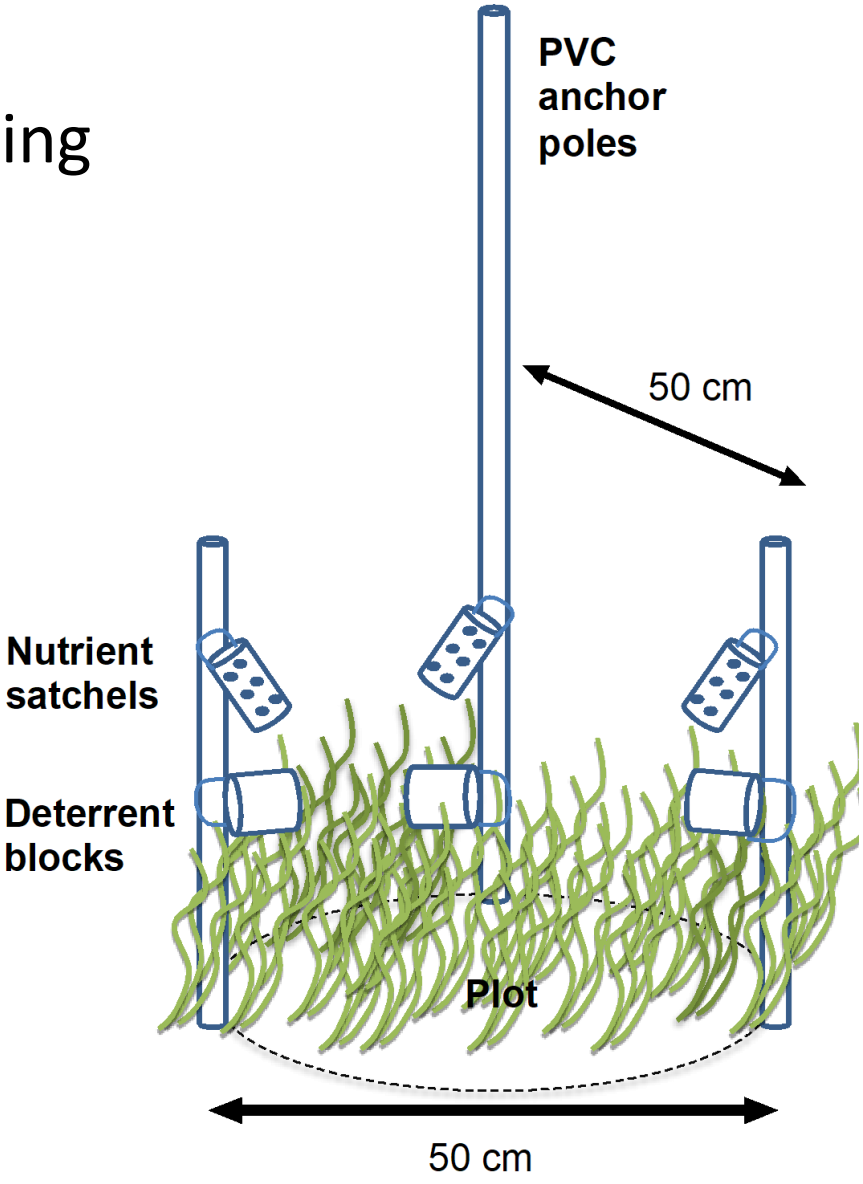
1.3 From ANOVA to SEM. Seagrass systems



1.3 From ANOVA to SEM. Experimental Design

What are the relative influence of top-down vs. bottom-up control in controlling seagrass ecosystems?





1.3 From ANOVA to SEM. Experimental Design

1.3 From ANOVA to SEM. Whalen et al. 2013

1.3 From ANOVA to SEM. Whalen et al. 2013

TABLE 1. Univariate analyses of mesograzer densities and epiphyte biomass from (A) fall and (B) summer experiments in an eelgrass (*Zostera marina*) bed in the York River, Virginia, USA.

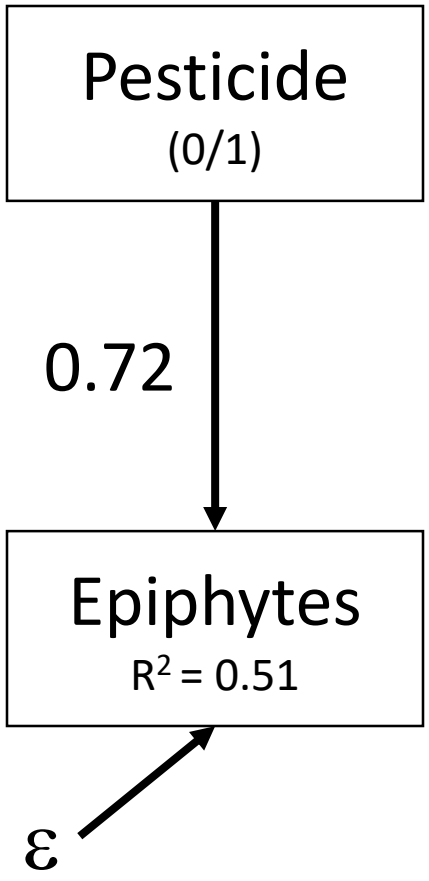
Experiment and response source	Crustaceans			Gastropods			Epiphytes		
	df	*F*	*P*	df	*F*	*P*	df	*F*	*P*
A) Fall									
Deterrent	1	42.84	**<0.001**	1	0.33	0.574	1	3.97	0.052
Fertilization							1	3.10	0.084
Sampling date	2	13.77	**<0.001**	2	0.12	0.887	1	78.24	**<0.001**
Det. × fert.							1	0.86	0.358
Det. × date	2	2.48	0.108	2	1.27	0.301	1	3.72	0.059
Fert. × date							1	7.00	**0.011**
Det. × fert. × date							1	0.81	0.371
Residual	21			21			51		
B) Summer									
Deterrent	1	129.24	**<0.001**	1	1.07	0.306	1	66.22	**<0.001**
Fertilization	1	0.00	0.958	1	0.01	0.920	1	2.19	0.145
Sampling date	1	0.89	0.349	1	11.00	**0.002**	1	0.83	0.367
Det. × fert.	1	0.10	0.756	1	2.00	0.163	1	1.00	0.322
Det. × date	1	0.58	0.448	1	2.96	0.091	1	6.21	**0.016**
Fert. × date	1	2.90	0.094	1	0.71	0.403	1	0.53	0.468
Det. × fert. × date	1	1.57	0.216	1	0.27	0.606	1	1.14	0.290
Residual	56			56			56		

Notes: ANOVA tables for linear models describe the effects of chemical deterrent, nutrient fertilization, and sampling date on crustacean mesograzer density, gastropod mesograzer density, and epiphyte biomass. All data were natural-log-transformed except summer gastropods (square-root transformed). Model terms were tested using *F* tests and type III sums of squares. Note that the analyses presented for the summer experiment are balanced. *P* values <0.05 are shown in boldface.

DEATH BY F-TABLES!

1.3 From ANOVA to SEM. ANOVA

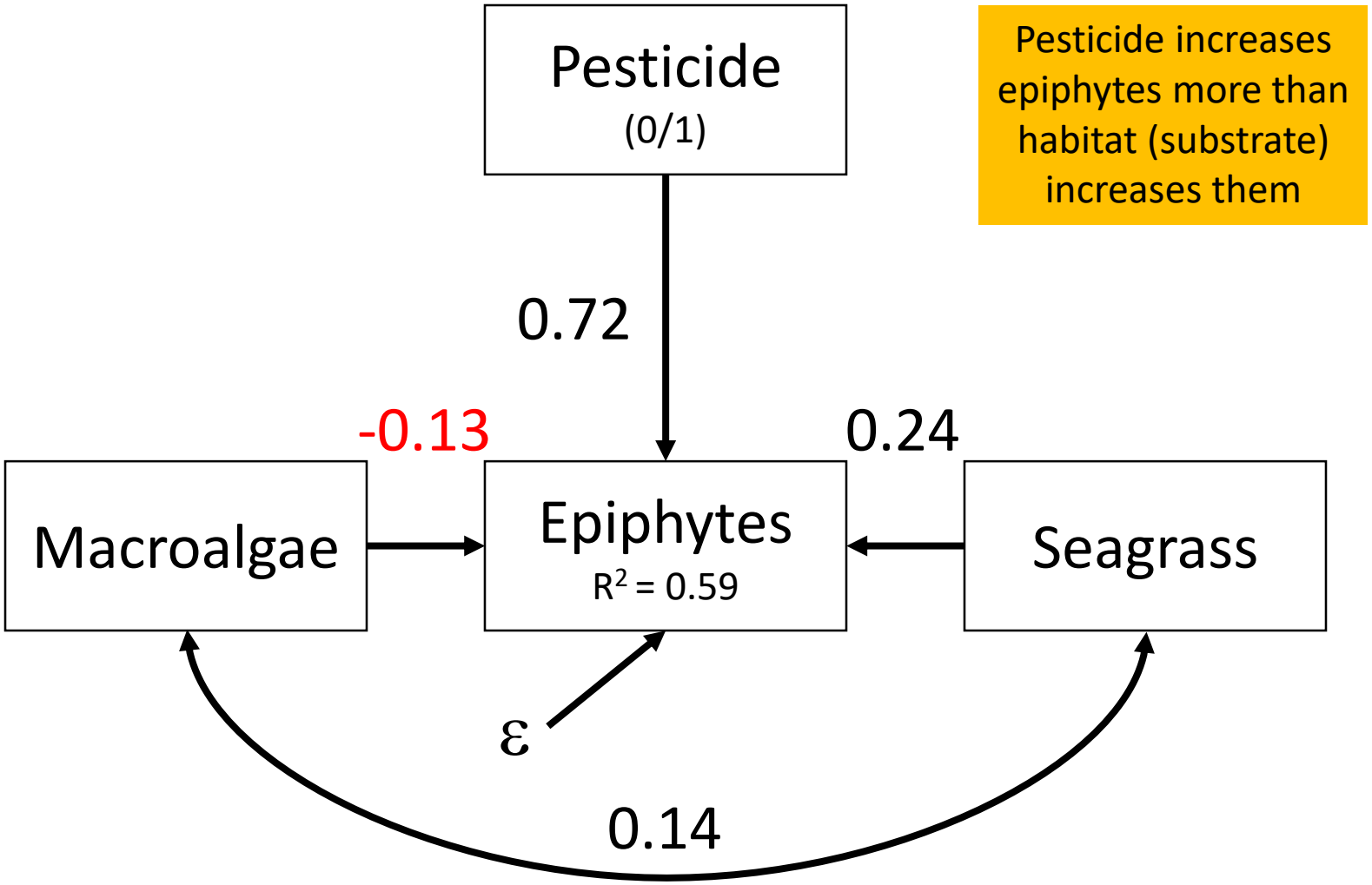
Epiphytes ~ Pesticide



Pesticide increases epiphytes

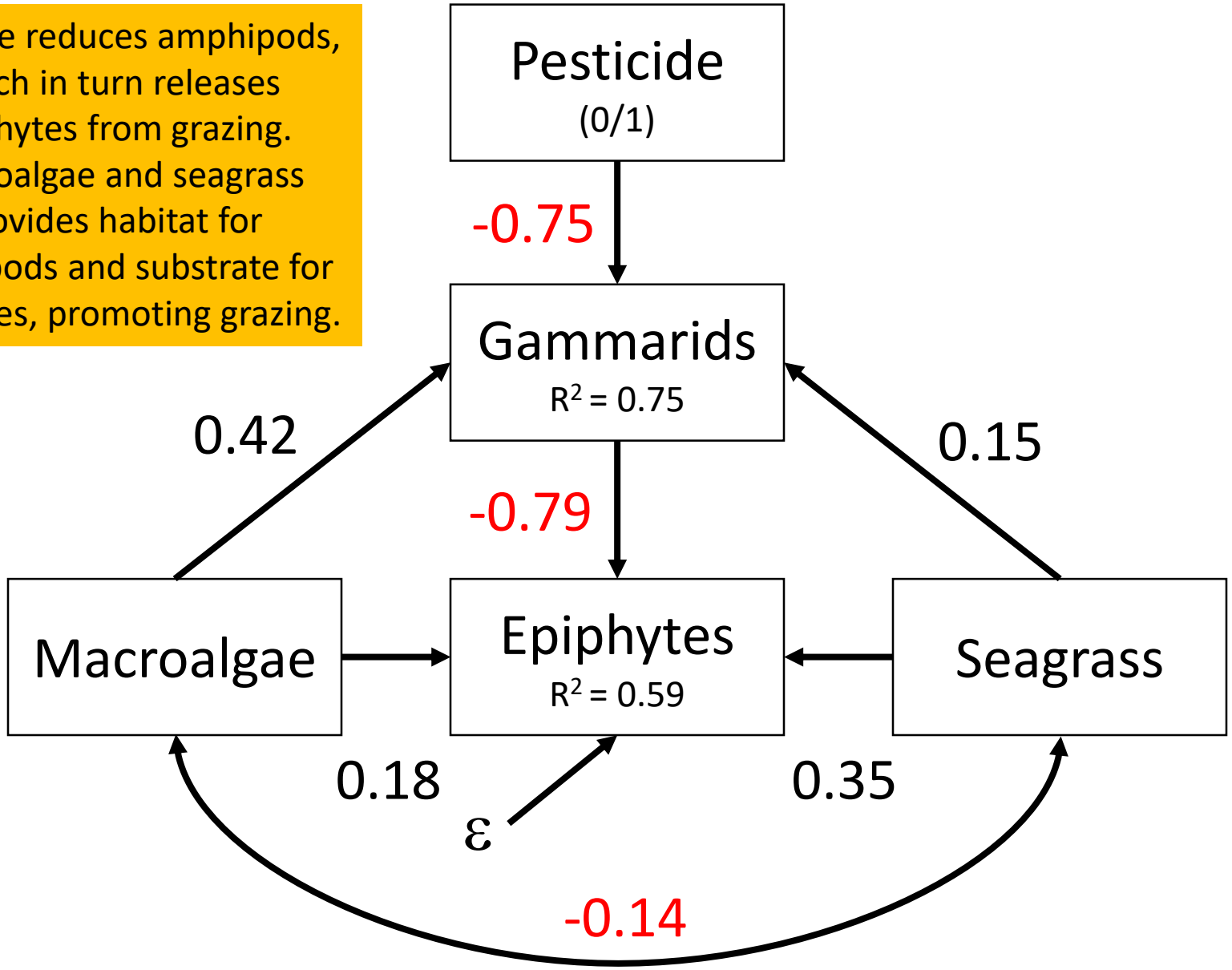
1.3 From ANOVA to SEM. ANCOVA

Epiphytes ~ Pesticide + Macroalgae + Seagrass

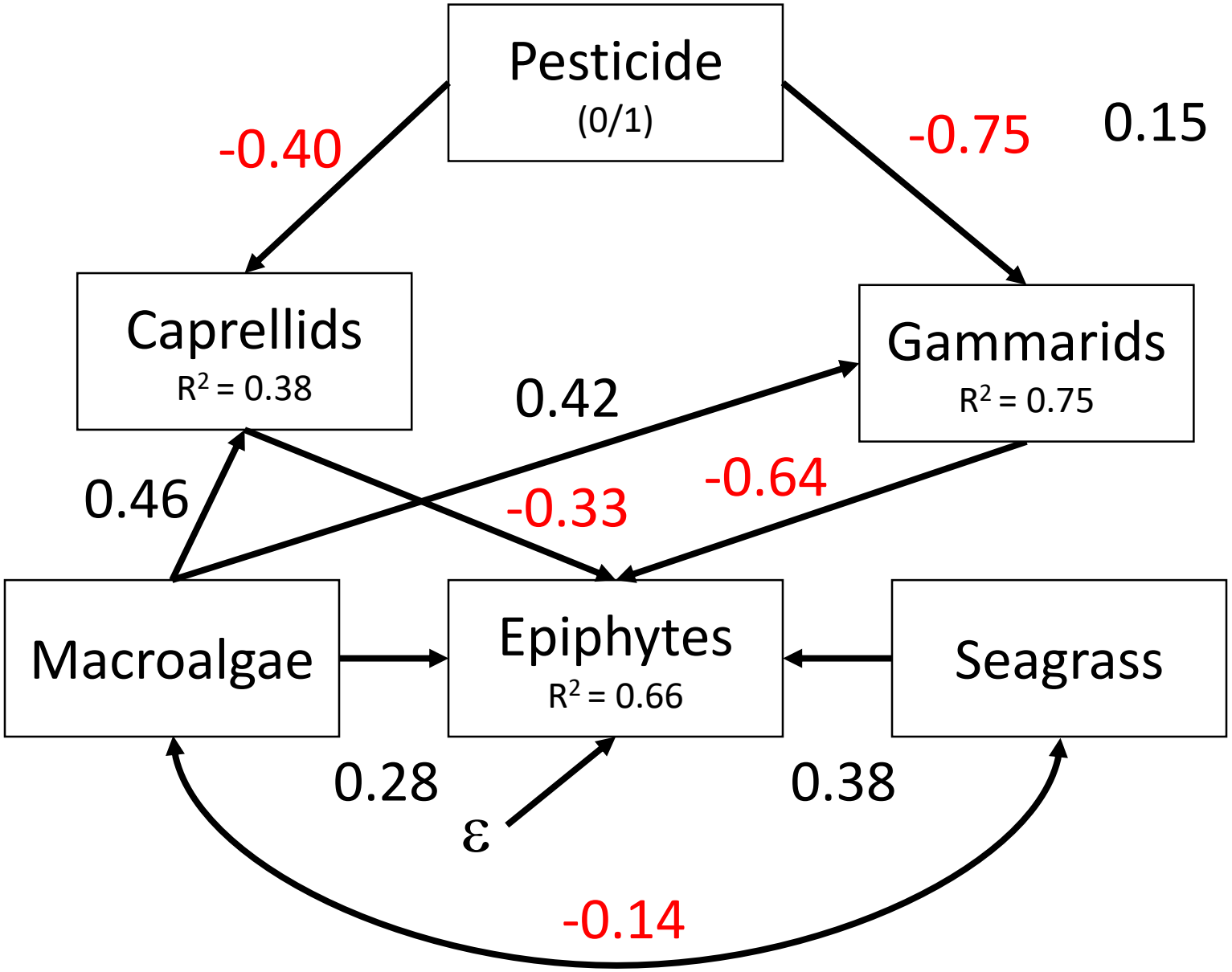


1.3 From ANOVA to SEM. Mediation

Pesticide reduces amphipods, which in turn releases epiphytes from grazing. Macroalgae and seagrass provides habitat for amphipods and substrate for epiphytes, promoting grazing.



1.3 From ANOVA to SEM. Mediation x2



1.3 From ANOVA to SEM. Increasing inference

Pesticide reduces epiphytes

ANOVA

Pesticide increases epiphytes more than habitat (substrate) increases them

ANCOVA

Pesticide reduces amphipods, which in turn releases epiphytes from grazing. Macroalgae and seagrass provides habitat for amphipods and substrate for epiphytes, promoting grazing.

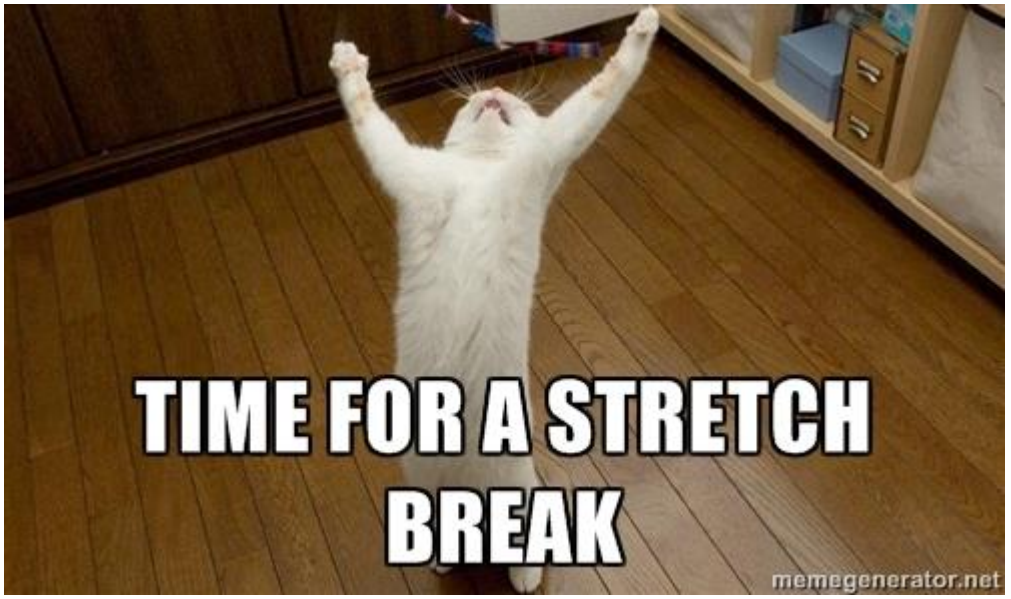
SEM

Pesticide reduces gammarid and caprellid amphipods, which in turn releases epiphytes from grazing. Gammarids appear to control epiphytes in this system. Macroalgae provides habitat for amphipods, promoting grazing, while eelgrass provides substrate for epiphytes.

Full SEM

1.3 From ANOVA to SEM. Increasing inference

- Teases out *complex relationships*
- Identification and comparison of di*rect vs. indirect effects* & potential mediators
- Precise *mechanistic* explanations


TIME FOR A STRETCH
BREAK
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