Structural Equation Modeling of Fish-Habitat Relationships

CHaMP Workshop

Cove, Oregon – June 2015

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Columbia River Inter-Tribal Fish Commission

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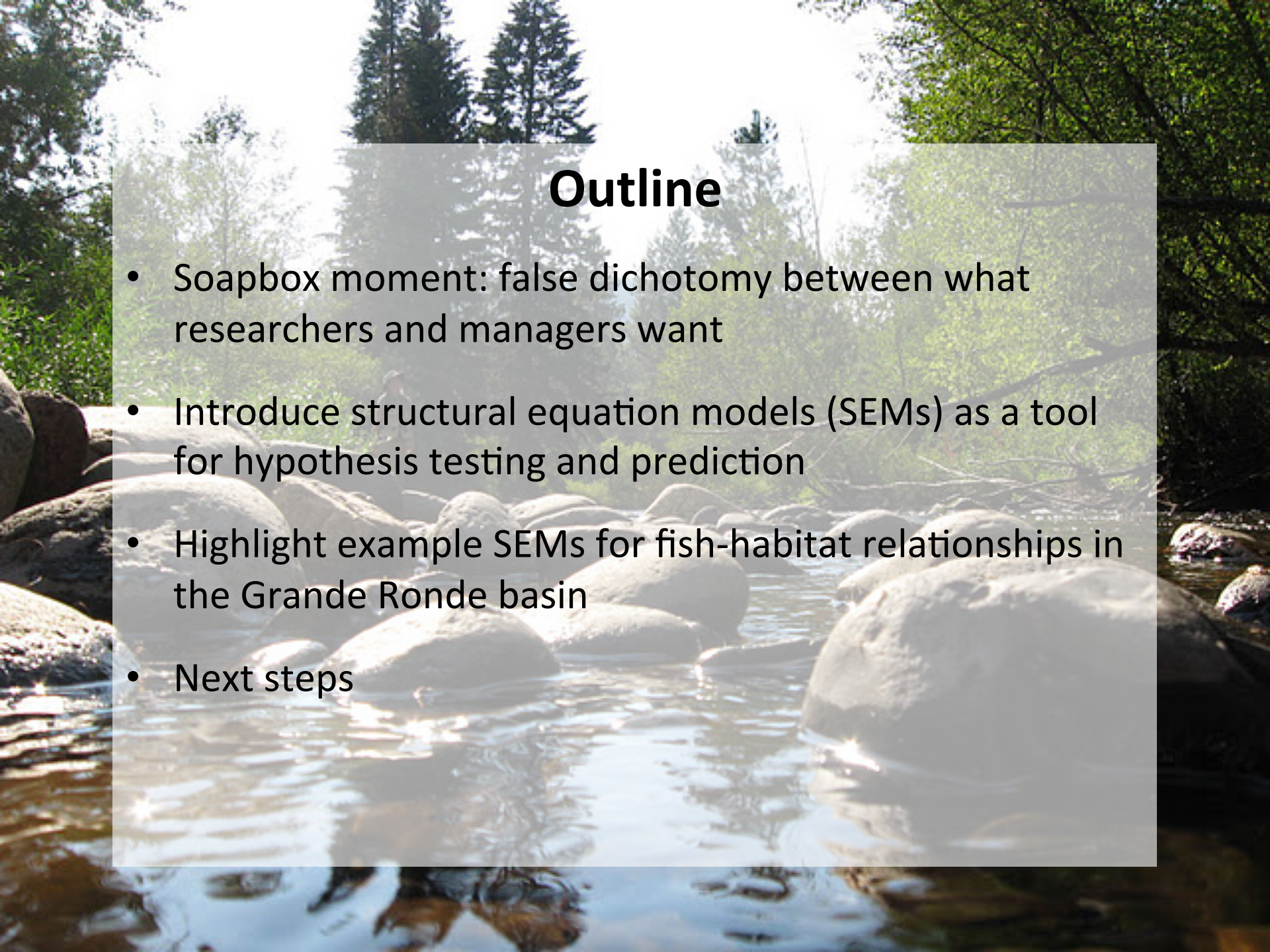
Tom Cooney, **NOAA**
Sean Sullivan, **Rhithron Assc.**

Funding:
BPA Project # 2009-004-00
BIA-RPI Climate Change



Outline

- Soapbox moment: false dichotomy between what researchers and managers want
- Introduce structural equation models (SEMs) as a tool for hypothesis testing and prediction
- Highlight example SEMs for fish-habitat relationships in the Grande Ronde basin
- Next steps

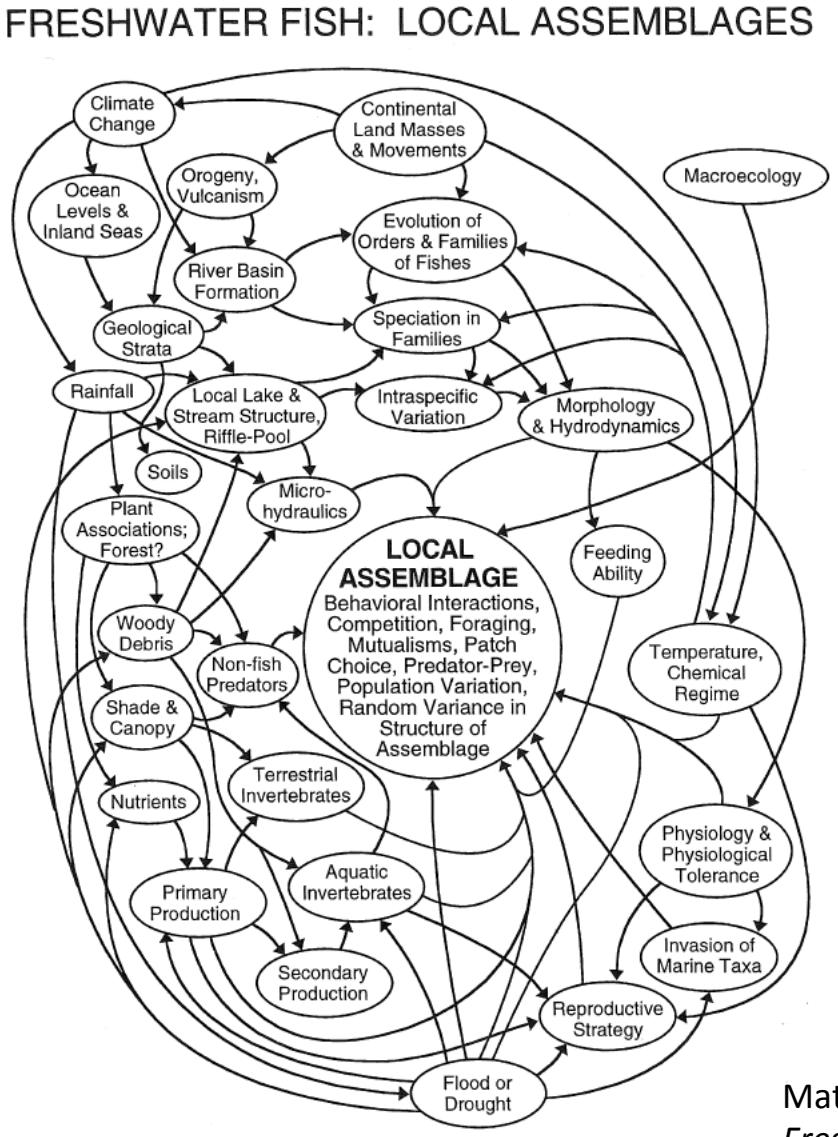
Information generated by CHaMP

2,218 metrics and growing…

Thalweg Depth Profile Filtered Mean	Thalweg Depth Profile Filtered CV	Centerline Depth Profile Filtered Mean	Centerline Depth Profile Filtered CV	Bankfull Width Profile Filtered Mean	Bankfull Width Profile Filtered CV	Bankfull WidthToDep Ratio Profile Filtered Mean	Bankfull WidthToDep Ratio Profile Filtered CV	Wetted Width Profile Filtered Mean	Wetted Width Profile Filtered CV	Wetted WidthToDep Ratio Profile Filtered Mean	Wetted WidthToDep Ratio Profile Filtered CV
0.37 m	0.5127	0.27 m	0.5953	27.08 m	0.3614	46.1384	0.4848	17.91 m	0.5045	56.7283	0.7826
0.17 m	0.3939	0.16 m	0.3913	5.55 m	0.2684	20.8417	0.3463	3.36 m	0.1867	33.5631	0.3235
0.20 m	0.3773	0.18 m	0.3816	6.06 m	0.4143	20.5742	0.4222	2.84 m	0.2793	25.8972	0.4735
0.37 m	0.4243	0.32 m	0.4843	8.23 m	0.1982	14.5792	0.2558	6.35 m	0.3676	28.5816	0.5268
0.18 m	0.3249	0.16 m	0.3386	7.59 m	0.3102	20.6168	0.3610	5.09 m	0.3078	38.1149	0.5664
0.18 m	0.4412	0.16 m	0.4313	15.67 m	0.2007	42.8595	0.3644	8.64 m	0.2394	73.1787	0.4045
0.16 m	0.5684	0.14 m	0.5037	16.94 m	0.2093	40.0464	0.3614	7.91 m	0.2905	76.0707	0.4893
0.38 m	0.2167	0.33 m	0.2602	10.46 m	0.2863	21.3730	0.4210	7.78 m	0.2807	28.7336	0.3228
0.30 m	0.2871	0.27 m	0.3112	8.87 m	0.4325	24.0991	0.5539	6.44 m	0.3680	32.0583	0.5355
0.34 m	0.3772	0.29 m	0.4447	16.29 m	0.1506	34.4355	0.3173	12.86 m	0.1391	57.5095	0.3873
0.24 m	0.4361	0.22 m	0.4682	2.11 m	0.3577	10.6000	0.5354	1.48 m	0.3841	11.0920	0.5460
0.38 m	0.2697	0.34 m	0.3031	12.25 m	0.1074	19.2844	0.1403	9.99 m	0.1262	41.8026	0.2542
0.45 m	0.2019	0.40 m	0.2656	13.19 m	0.0985	15.9811	0.1427	10.36 m	0.1115	33.1940	0.2215
0.36 m	0.3198	0.26 m	0.4672	17.20 m	0.3000	39.6022	0.4538	12.08 m	0.3729	49.0943	0.5843
0.27 m	0.3485	0.24 m	0.3933	16.81 m	0.2463	32.1681	0.2973	12.76 m	0.2930	75.9139	0.5308
0.10 m	1.1984	0.08 m	1.0464	6.05 m	0.1722	34.3382	0.3063	3.27 m	0.3288	62.9278	0.5443
0.12 m	0.5106	0.12 m	0.5120	3.68 m	0.2503	16.6055	0.2942	2.46 m	0.3082	23.2092	0.5419
0.28 m	0.3206	0.24 m	0.3759	16.39 m	0.1335	31.5066	0.1812	13.57 m	0.1826	72.1229	0.3937
0.21 m	0.2648	0.18 m	0.2872	10.22 m	0.2271	31.3761	0.2955	6.67 m	0.2472	41.7621	0.3828
0.31 m	0.6343	0.30 m	0.6633	8.64 m	0.3879	20.0947	0.5042	5.10 m	0.3729	27.2018	0.5883
0.35 m	0.2333	0.29 m	0.3758	10.81 m	0.2729	26.6742	0.3825	8.97 m	0.2666	38.9286	0.5548

Fish-Habitat Relationships are Complex

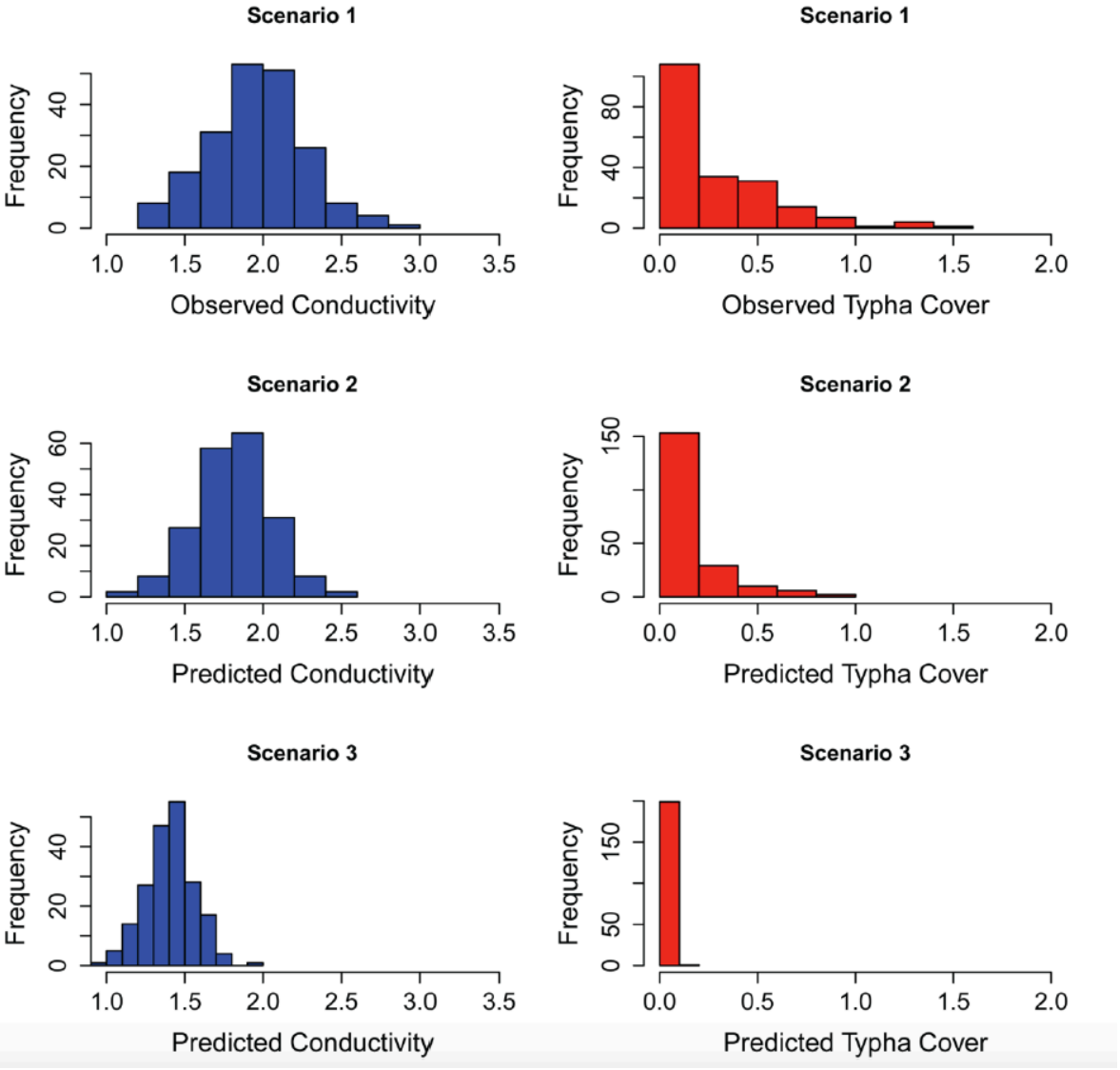
Job security for a fish habitat scientist?



Matthews 1998. *Patterns in Freshwater Fish Ecology*.

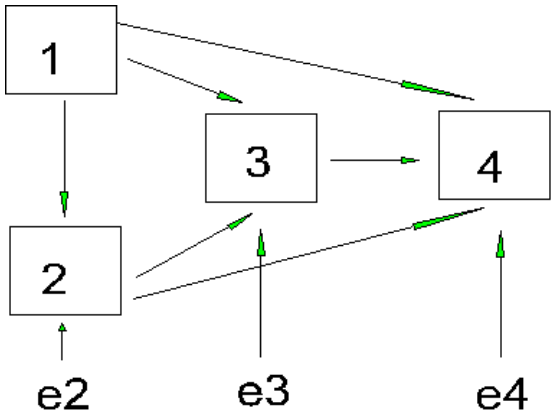
Providing useful management tools

Scenarios predicting invasive cattail cover



Grace et al. 2012. Guidelines for a Graph-Theoretic Implementation of Structural Equation Modeling. *Ecosphere* 3 (8)

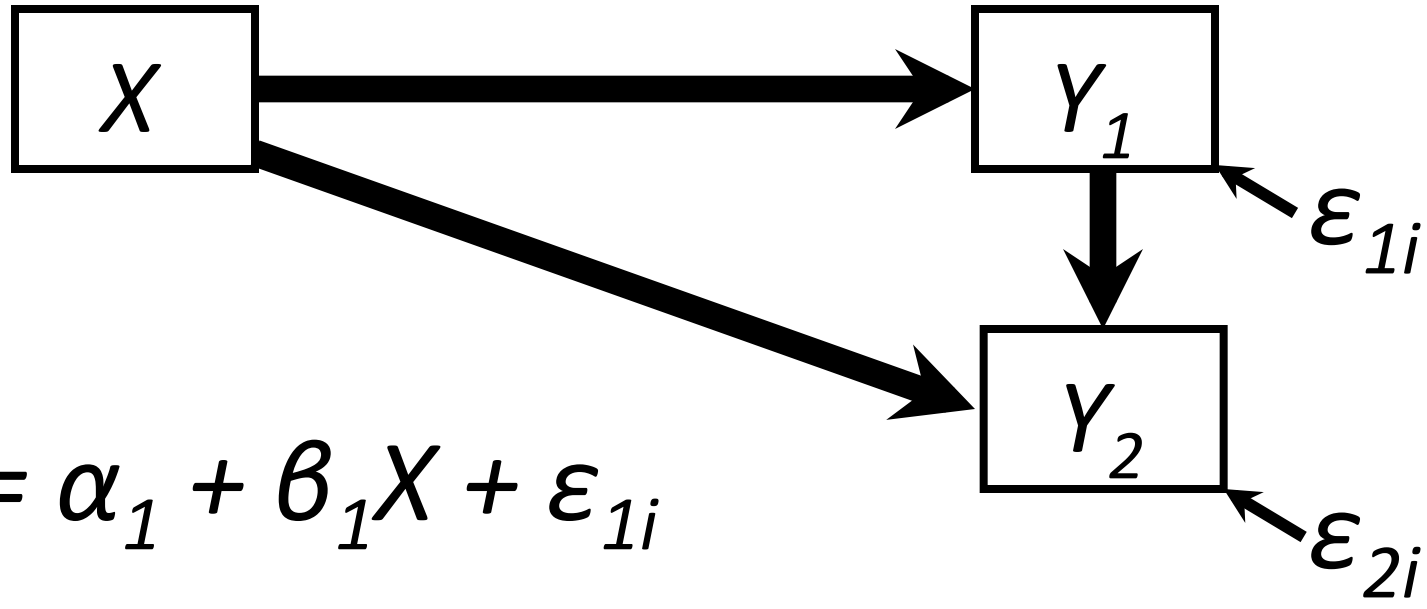
Structural Equation Modeling



- Path analysis developed by Sewall Wright (1918, 1921) to understand multiple causes and multiple responses
- Modern SEM involves analysis of covariance matrix to reveal causal relationships
- Model building and evaluation best represented graphically

Structural equation modeling

Grace, J.B. 2006. *Structural Equation Modeling and Natural Systems*. Cambridge, NY: Cambridge University Press.



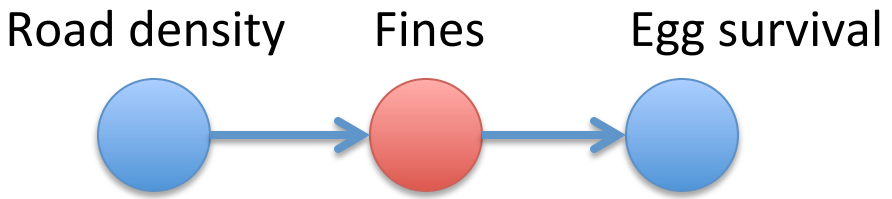
$$Y_1 = \alpha_1 + \beta_1 X + \varepsilon_{1i}$$

$$Y_2 = \alpha_2 + \beta_2 X + \beta_3 Y_1 + \varepsilon_{2i}$$

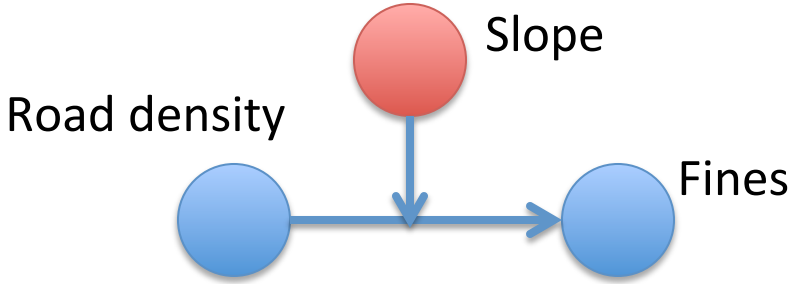
Language for causal models

Kathi Irvine, USGS; Wu & Zumbo 2008; Grace 2010; MacKinnon et al. 2012

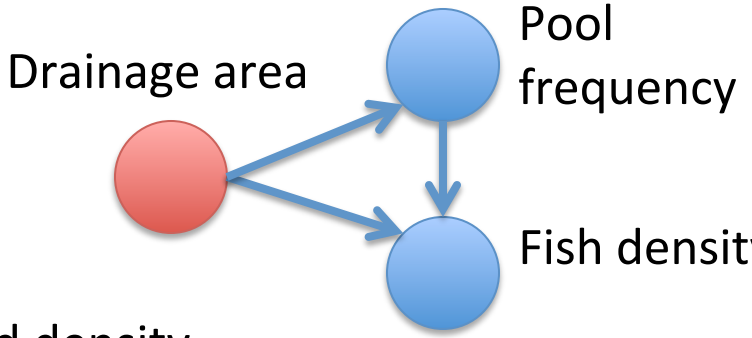
Mediator –how one independent variable effects a dependent variable



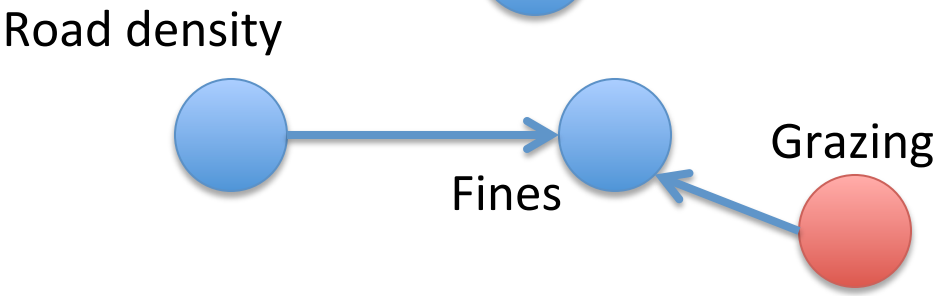
Moderator –contextual variable that modifies direction or strength of effect



Confounder –variable associated with both independent and dependent variables

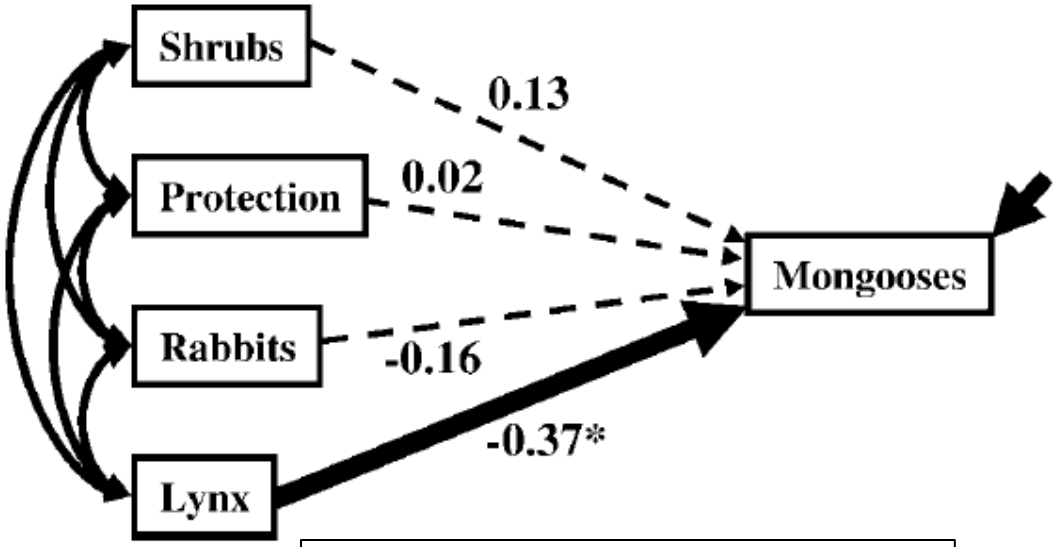


Covariate –variable associated dependent variable



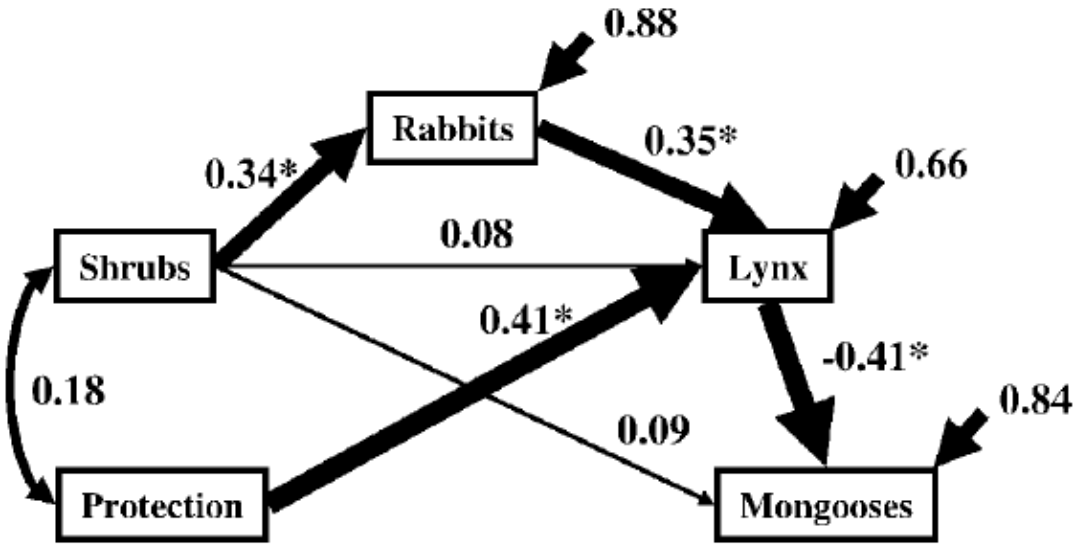
Mongoose & Lynx in SW Spain

- Multiple linear regression reveals that lynx reduce mongoose populations



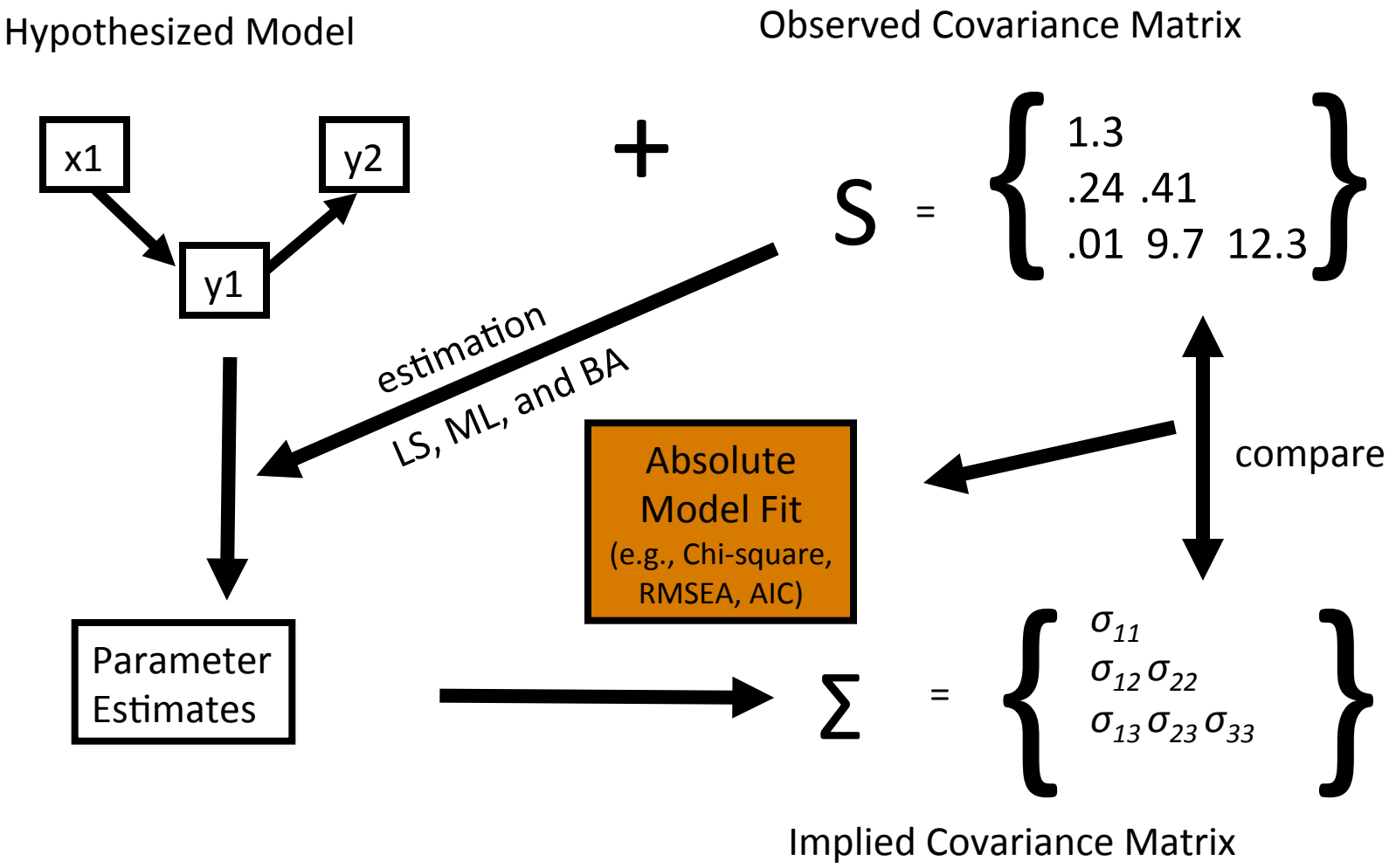
From Palomares *et al.* 1998, *J. Animal Ecology*

- SEM reveals a more informative story…



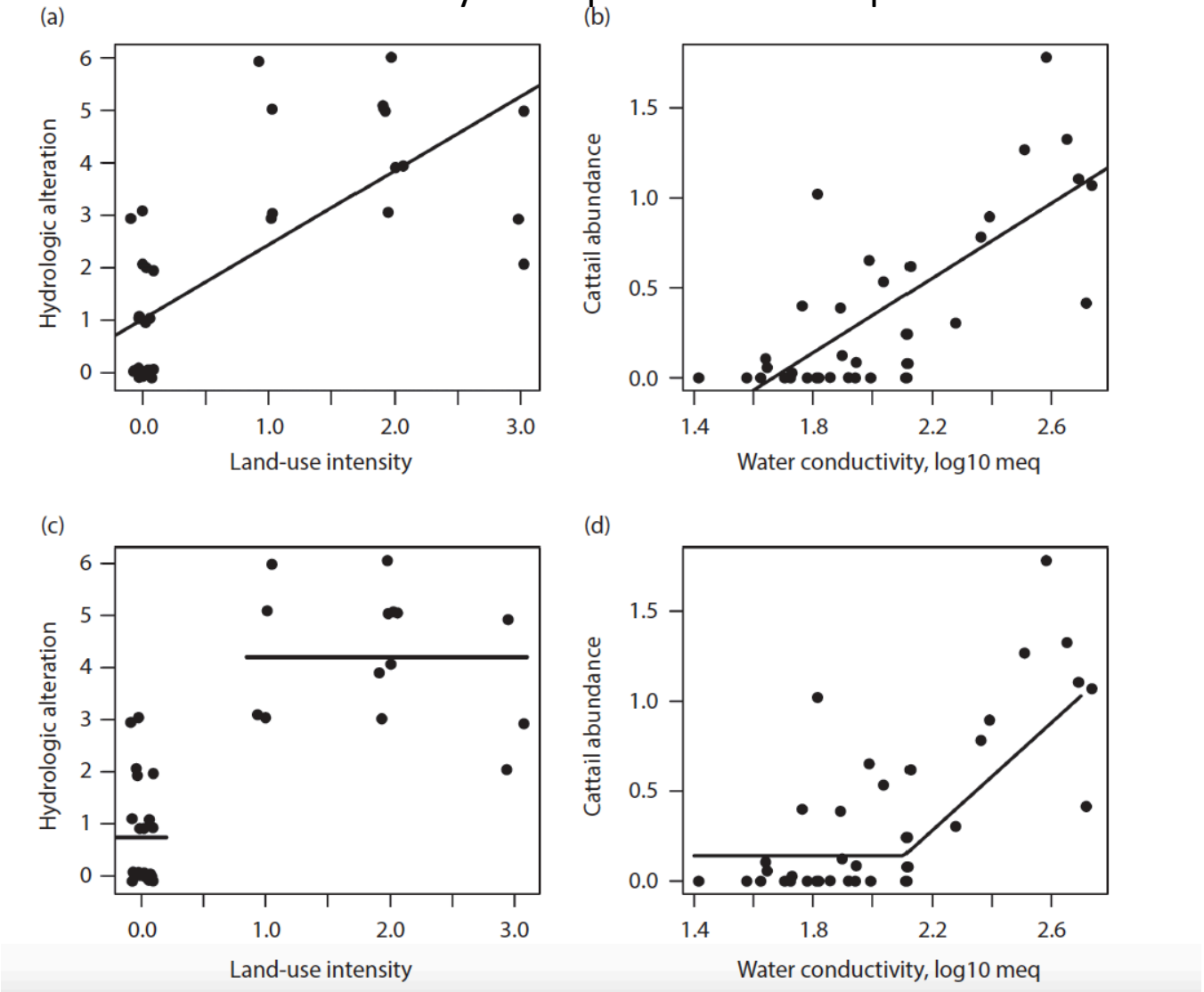
Estimation and Evaluation

"Model-based framework" (Courtesy Jim Grace)



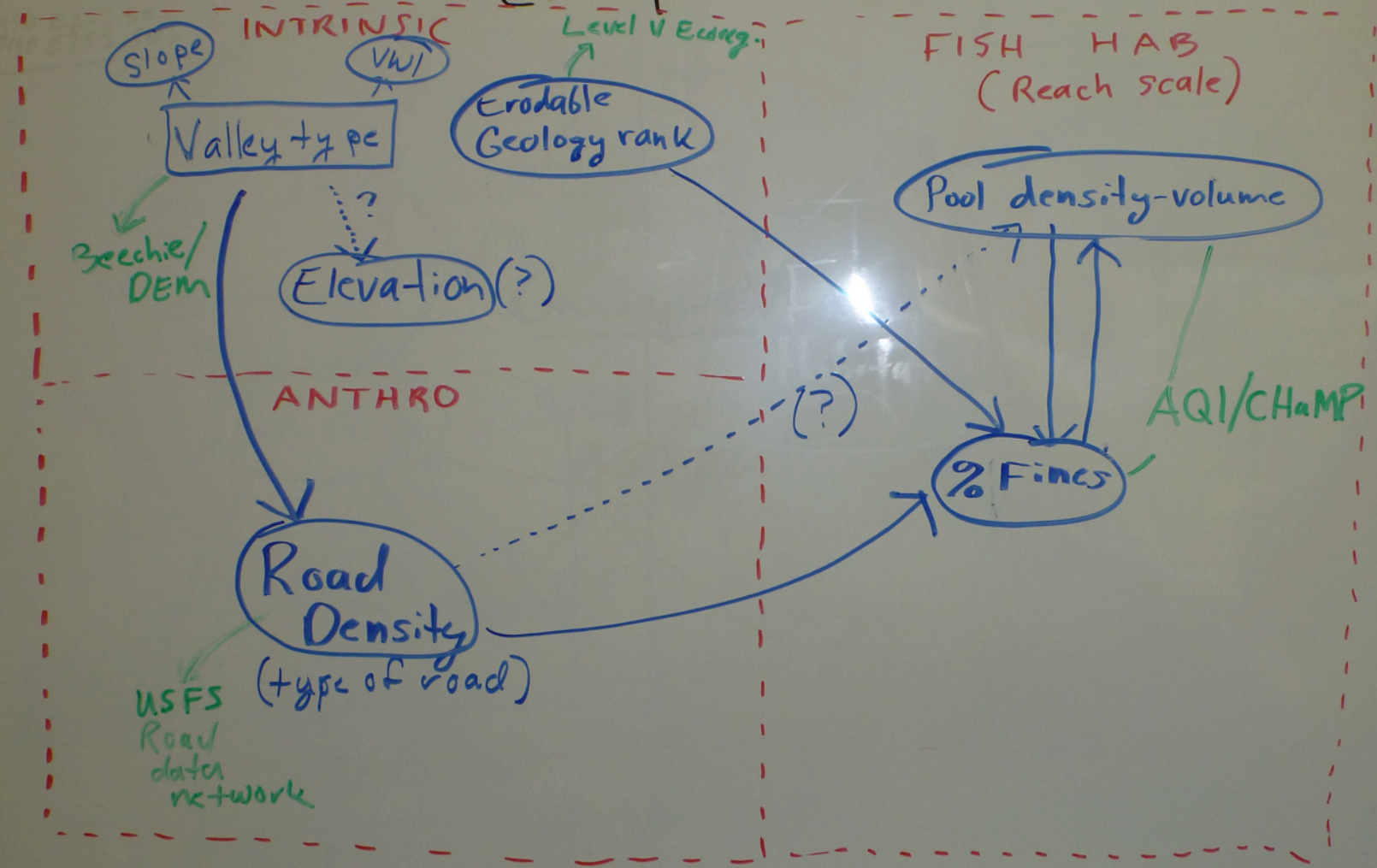
One advantage of local estimation

Flexibility in shape of relationships

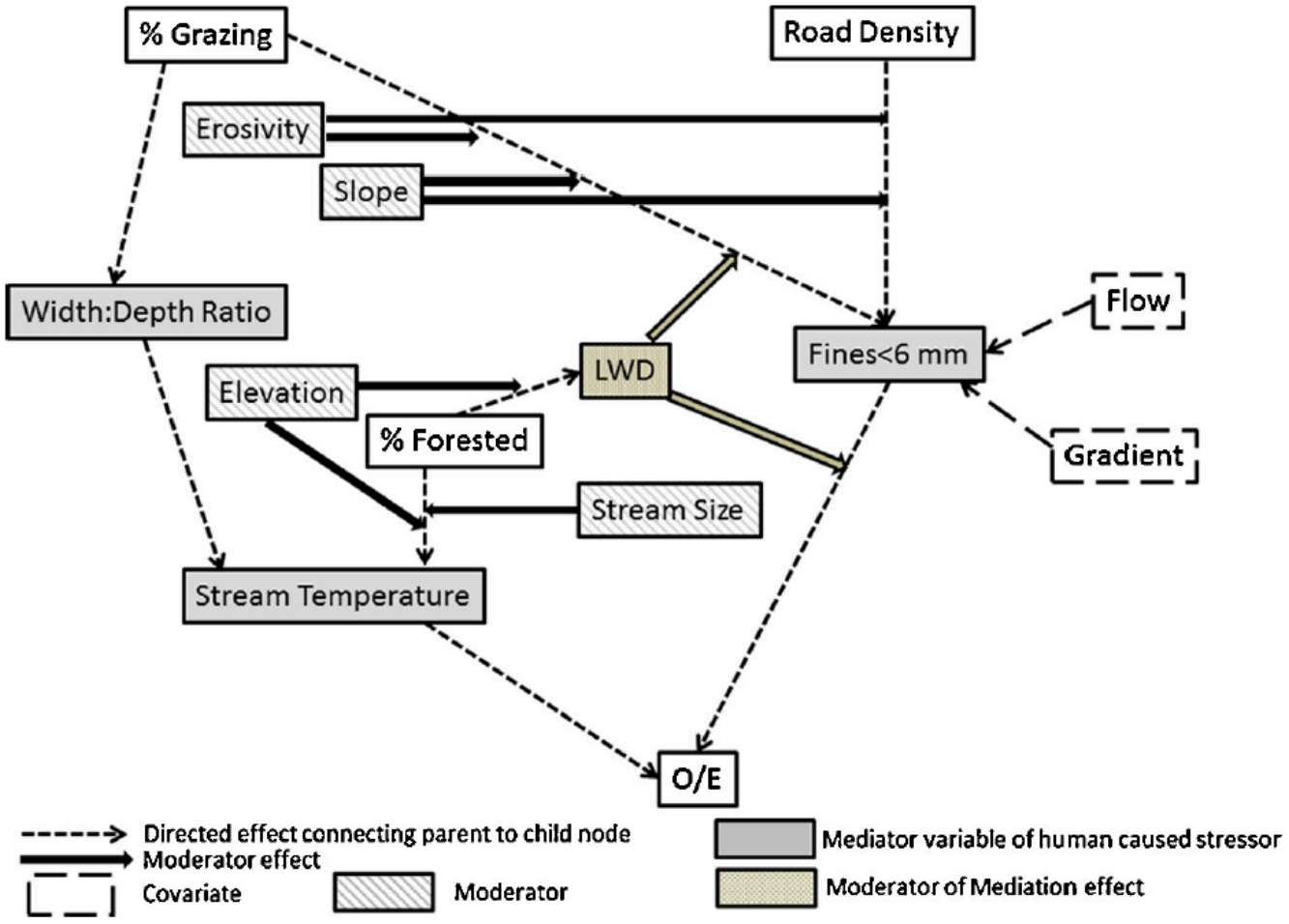


Grace et al. 2015. Structural Equation Modeling: Building and Evaluating Causal Models. In *Ecological Statistics: Contemporary Theory and Application*, edited by Fox et al., Oxford University Press.

9/12/2011 Fig.2b TS/SW
Example SEM

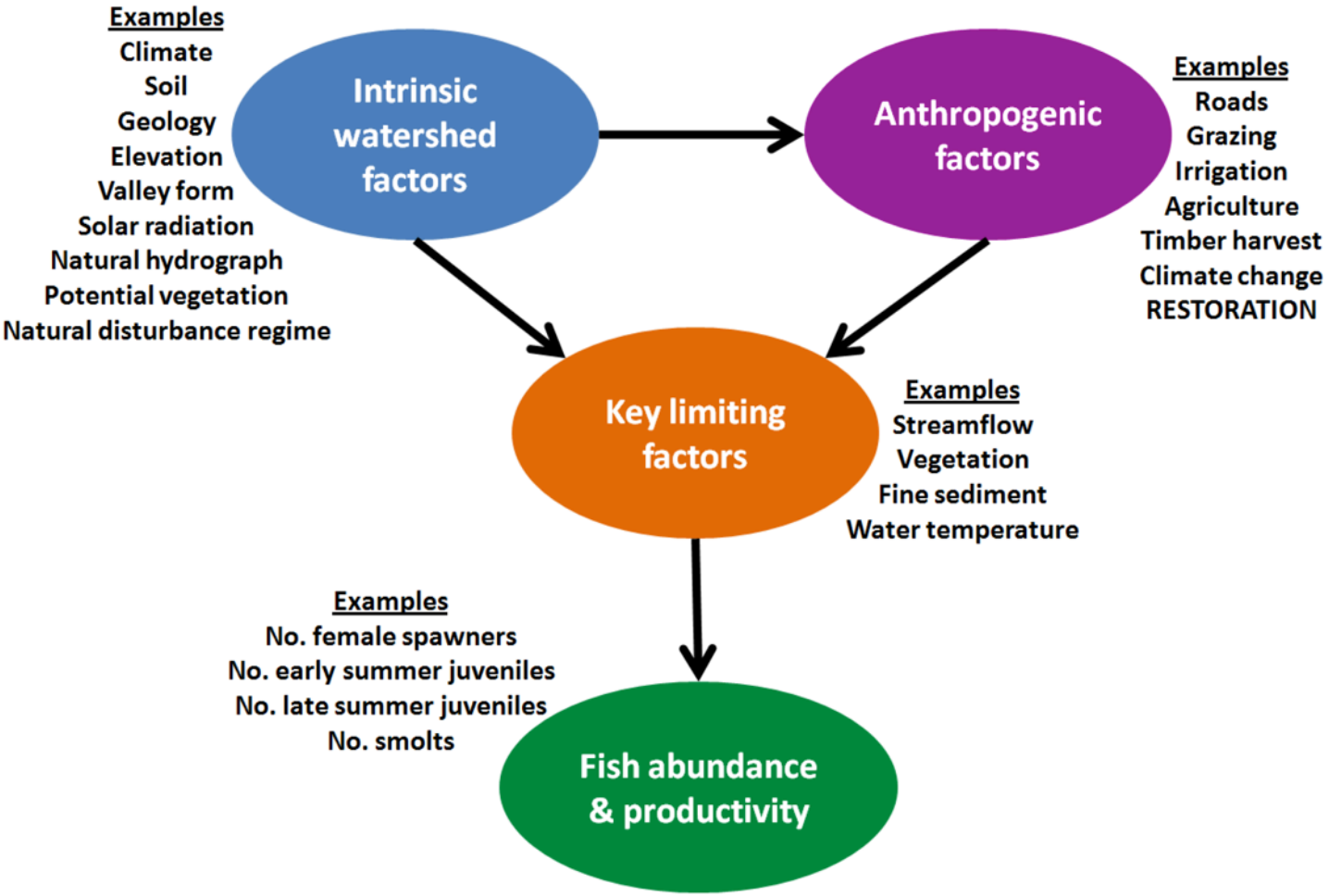


Hypothesized land use-bug relationships in PIBO



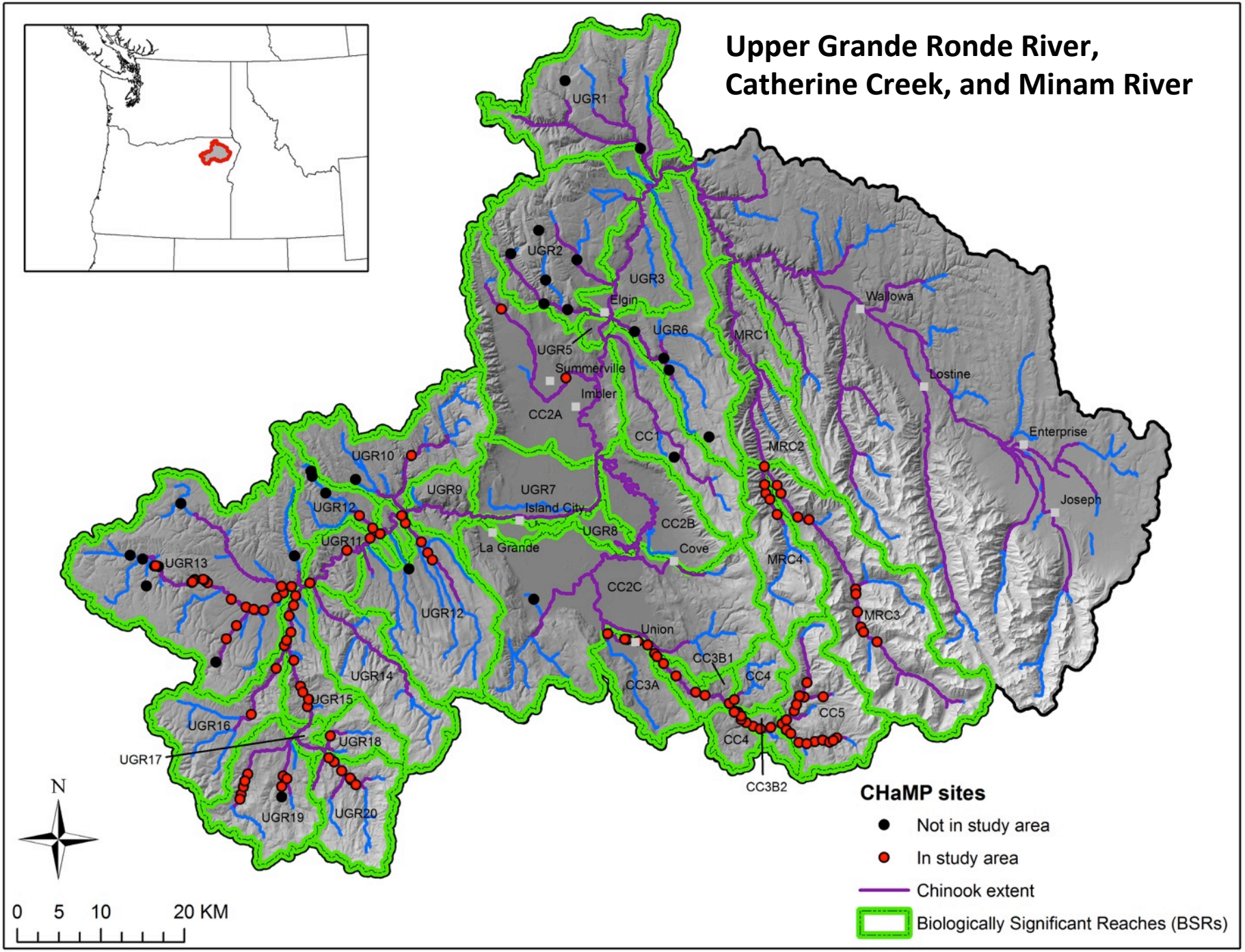
Irvine et al. 2015. Empirical Evaluation of the Conceptual Model Underpinning a Regional Aquatic Long-Term Monitoring Program Using Causal Modelling. *Ecological Indicators* 50: 8–23.

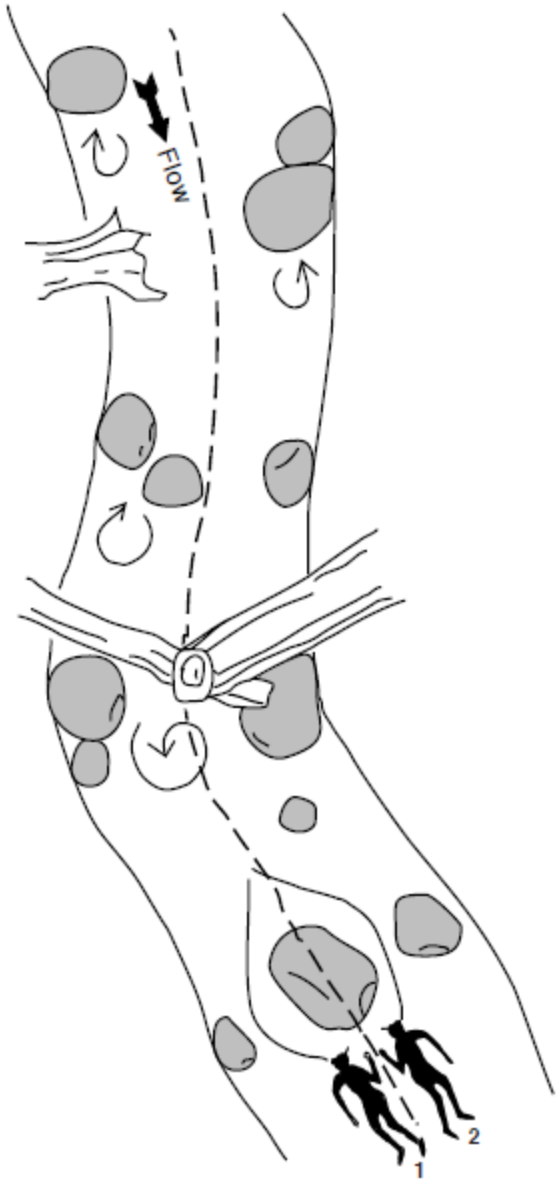
Conceptual framework for modeling fish productivity & capacity



Upper Grande Ronde & Catherine Creek - Current Habitat Condition

- Spring Chinook salmon and steelhead are ESA-listed species
- Upper Grande Ronde and Catherine Creek listed as “Critical Habitat”
- Heavily degraded habitat from timber harvest, agriculture and irrigation, and cattle grazing


Upper Grande Ronde River,
Catherine Creek, and Minam River
UGR1
UGR2
UGR3
Elgin
UGR6
UGR5
Summerville
Imbler
CC2A
CC1
UGR10
UGR9
UGR7
Island City
UGR12
UGR8
CC2B
La Grande
Cove
UGR11
UGR13
CC2C
UGR12
Union
CC3B1
CC4
CC3A
UGR14
UGR15
CC5
UGR16
UGR18
CC4
UGR17
CC3B2
UGR19
UGR20
Wallowa
MRC1
Lostine
Enterprise
MRC2
Joseph
MRC4
MRC3
N
0 5 10 20 KM
CHaMP sites
Not in study area
In study area
Chinook extent
Biologically Significant Reaches (BSRs)



Snorkel & benthic macroinvertebrate surveys at CHaMP sites

- Abundance & density of salmonids by species & size class (Thurow 1994, O'Neal 2007), relative abundance non-salmonids
- Coupled with benthic macroinvertebrate sampling

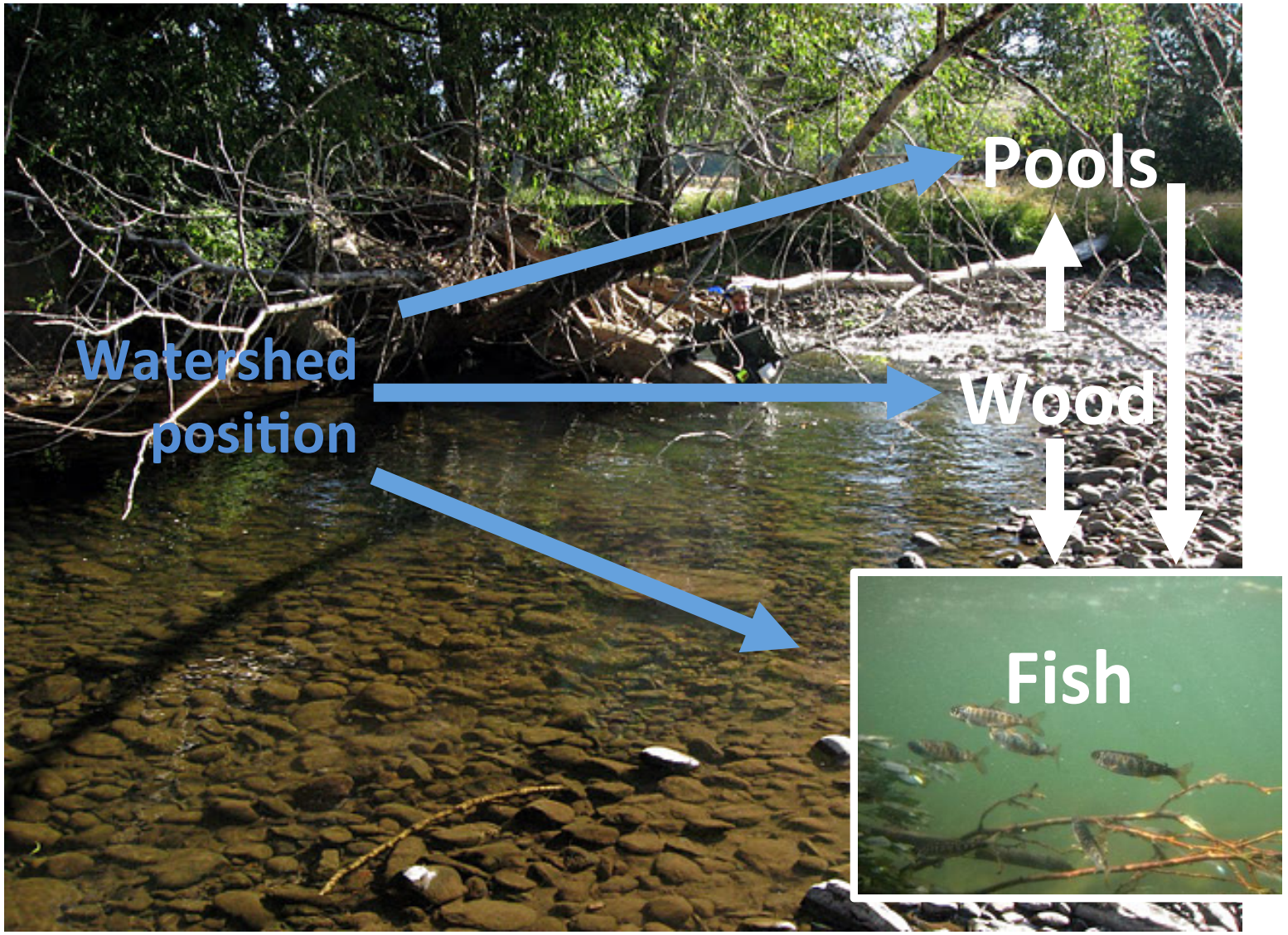
An example:

Restoration via wood placement & recruitment

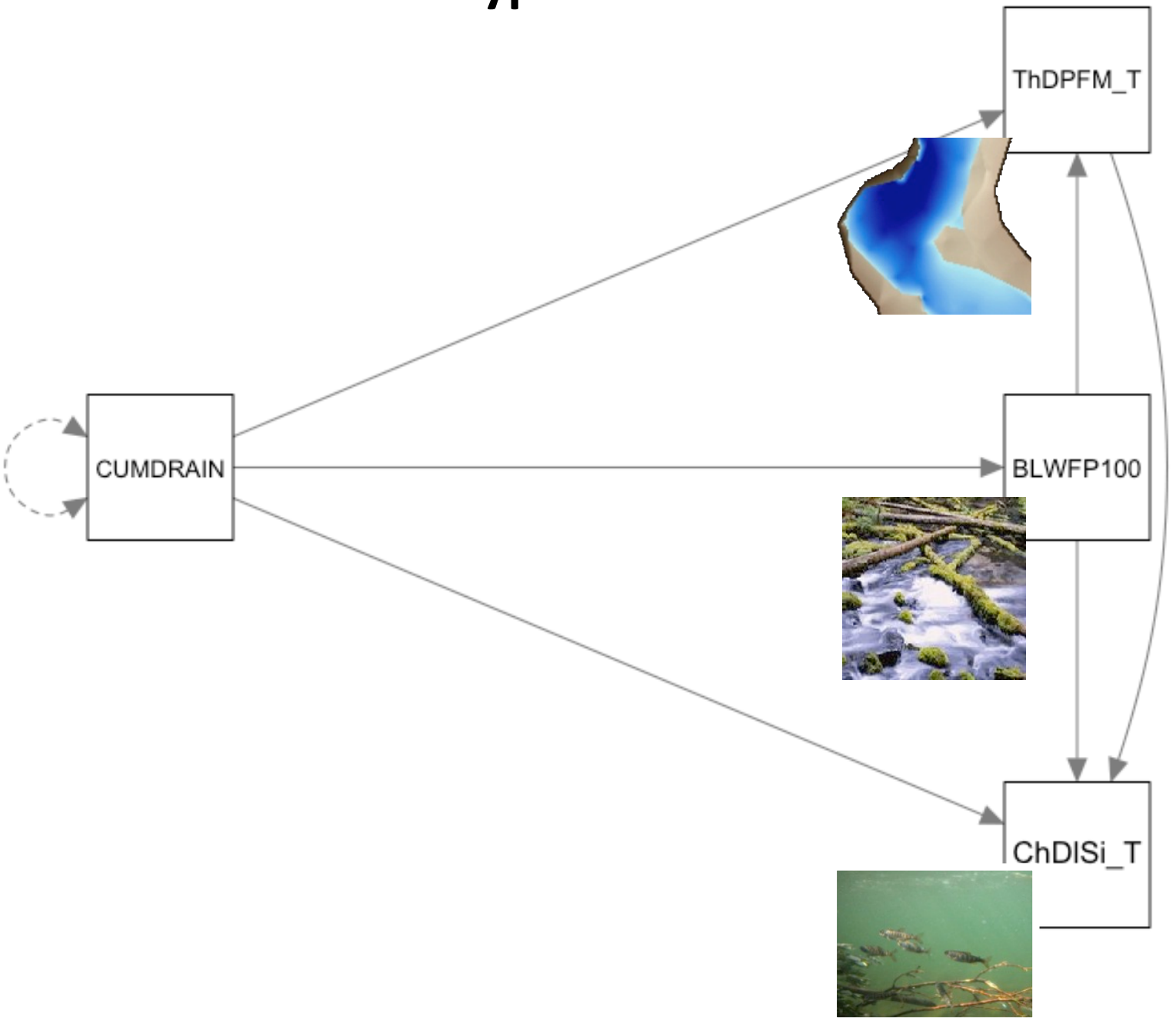
Naturally-recruited wood

Wood placement

Interaction among wood, pools, and juvenile Chinook

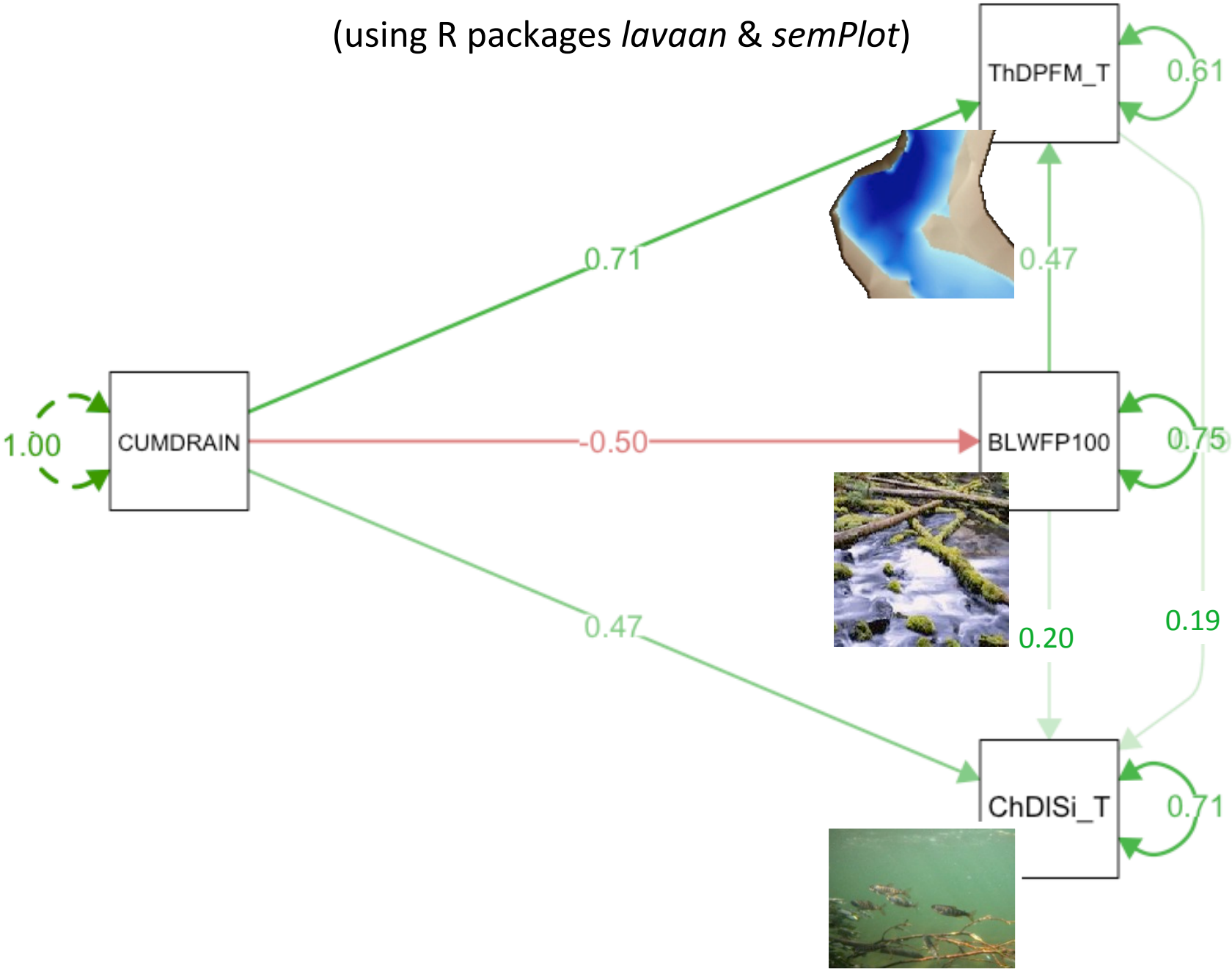


SEM Hypotheses for Fish



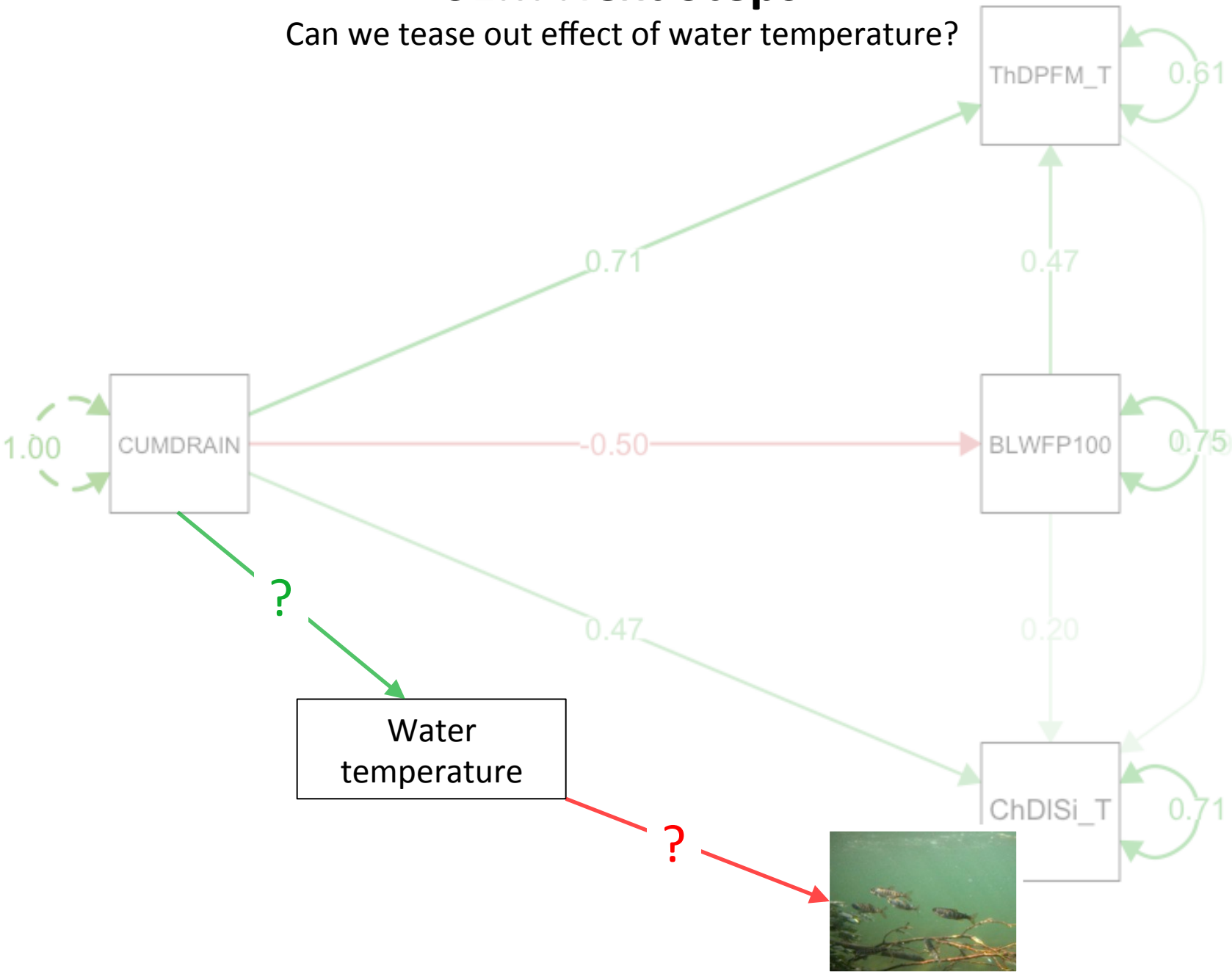
SEM Results for Fish

(using R packages *lavaan* & *semPlot*)

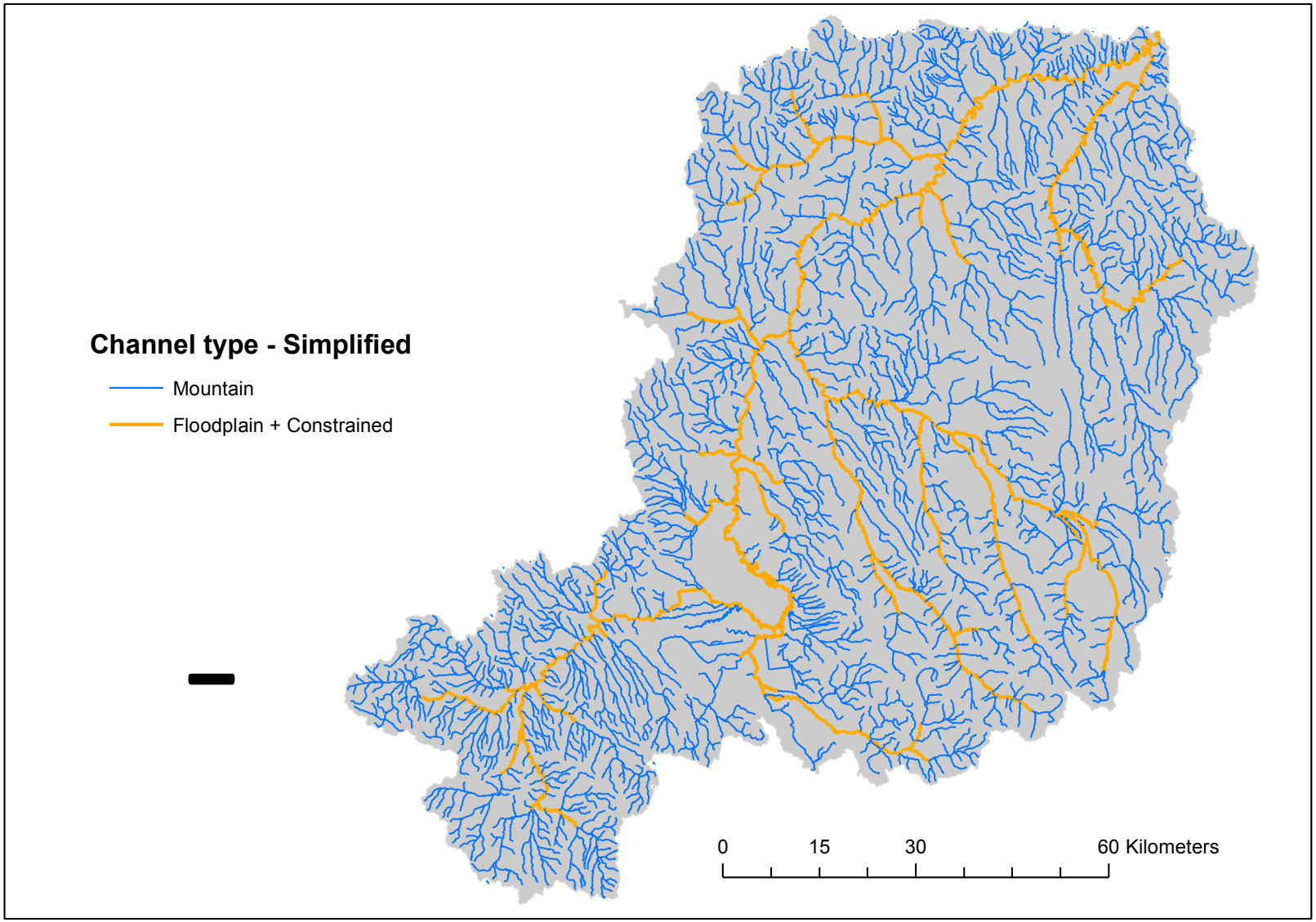


SEM Next Steps

Can we tease out effect of water temperature?

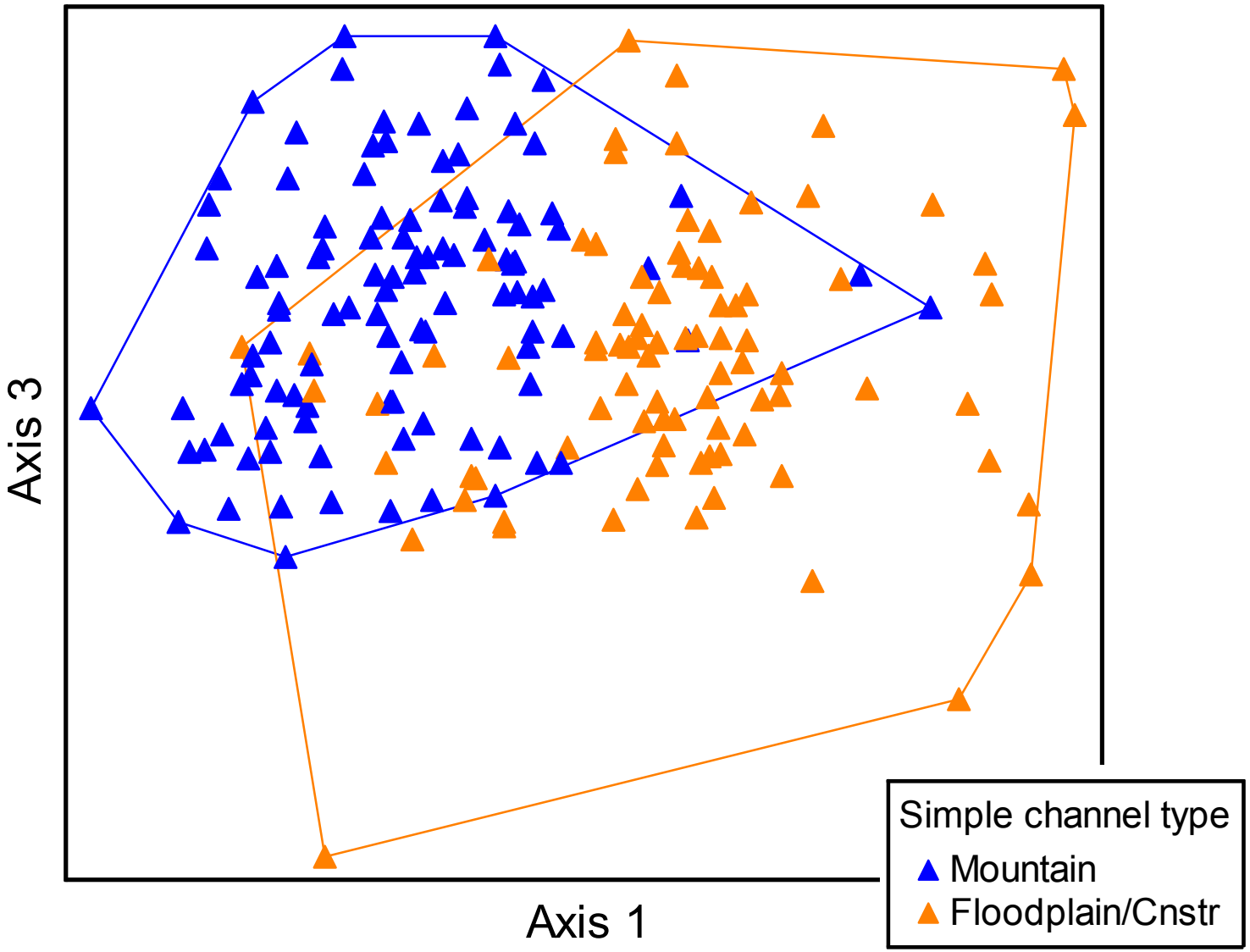


Multi-group SEM example: fish-habitat relationships differ by river type

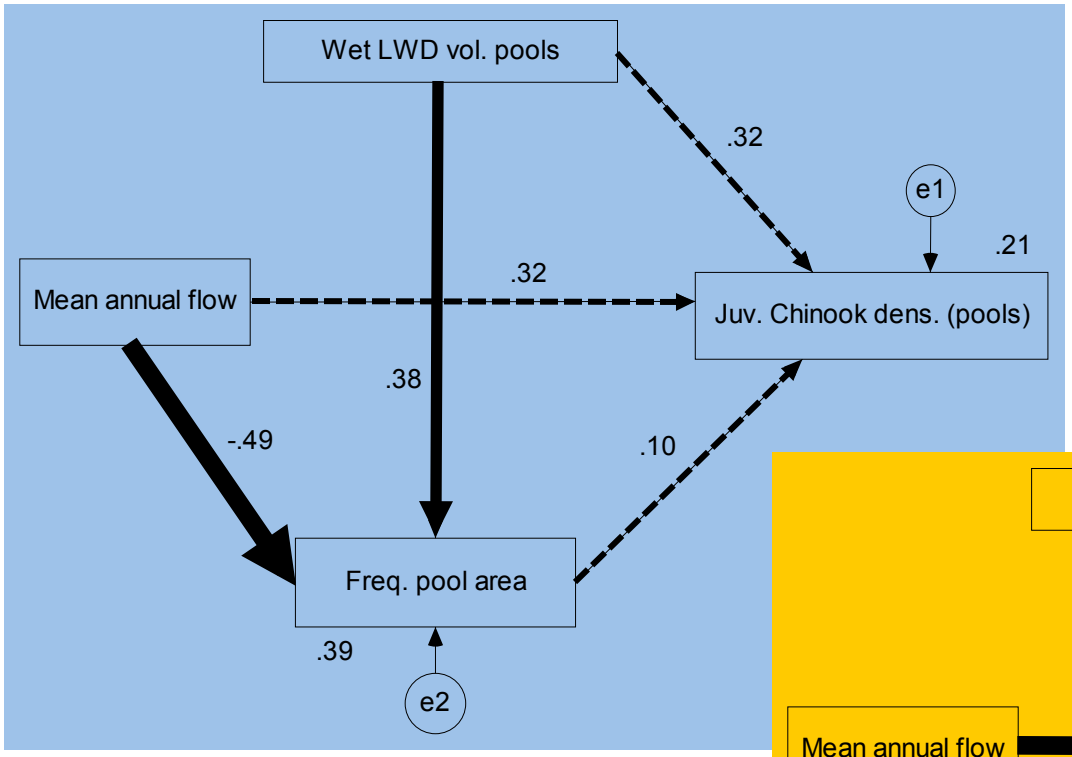


Multi-group SEM example: fish-habitat relationships differ by river type

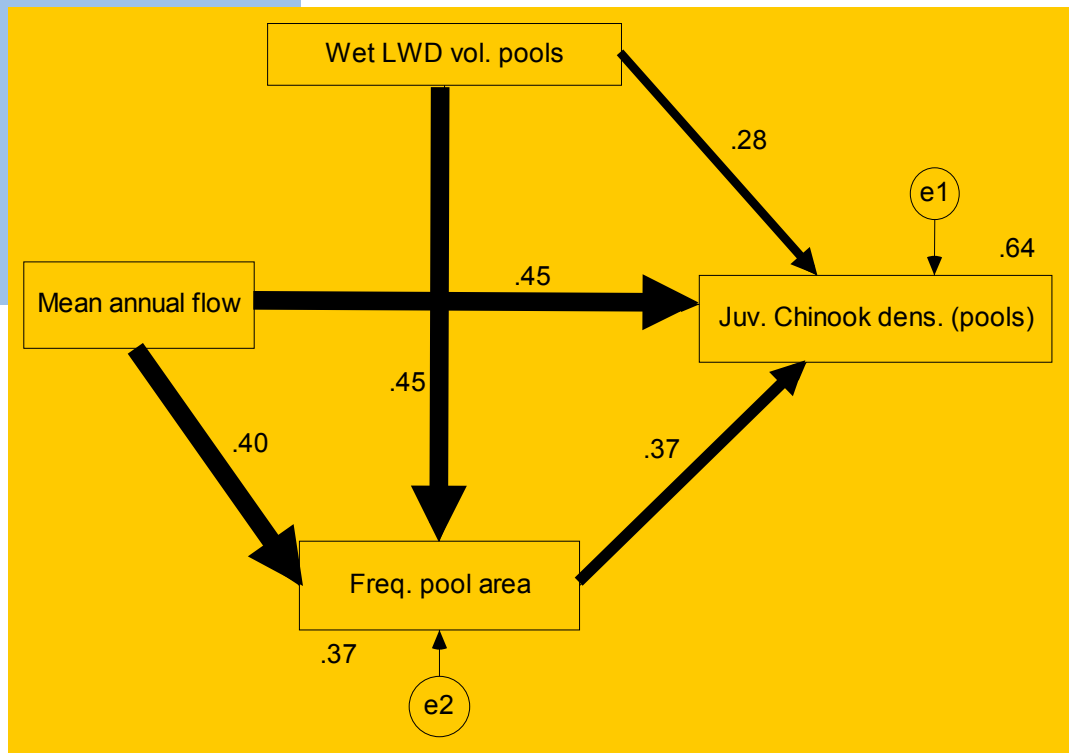
NMDS ordination of CHaMP habitat metrics



Multi-group SEM example: fish-habitat relationships differ by river type



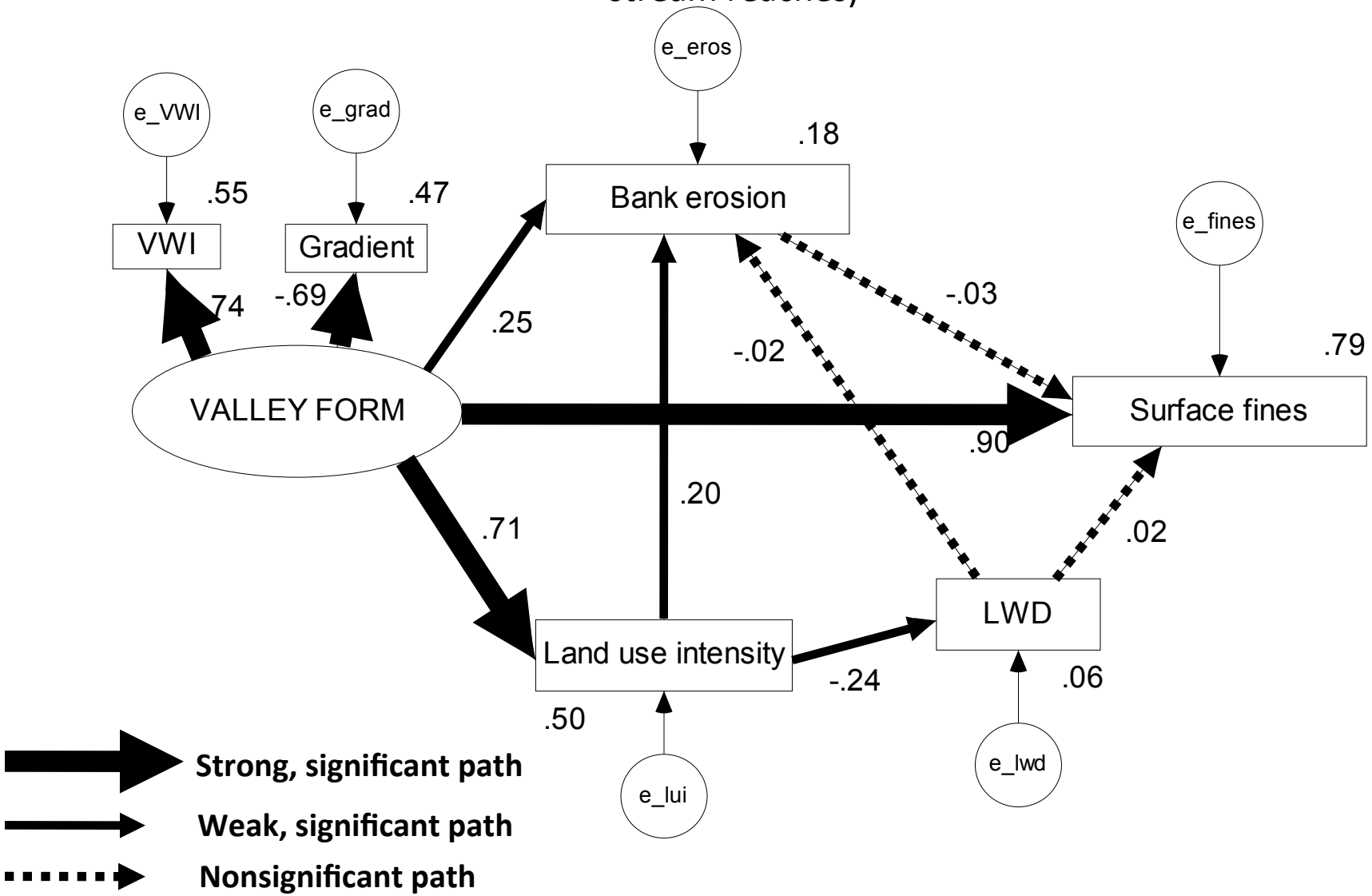
"Mountain"



"Floodplain & Constrained"

Latent variable example:

Using ODFW Aquatic Inventories data to test landscape-fish habitat hypotheses (*n* = 104 stream reaches)



Three useful software packages

AMOS (SPSS)

- Proprietary (free student version exists)
- User-friendly: models constructed via diagram building
- Handles most common SEM applications
- Modification indices ONLY if no missing data

lavaan & semPlot packages in R

- Free, open-source
- Good documentation, plenty of features
- Learning curve: model building via writing code
- Modification indices, even if missing data
- Additional packages include complex survey designs, learning modules, other…

MINE package in R (Reshef et al. 2011. *Science* 334)

- Free, open-source
- Finds best bivariate relationships, linear or non-linear
- USE WITH CAUTION!!!

Next steps

- Get Matt Nahorniak's cell number (incorporate design weights)
- Move from hypothesis testing to prediction
  - Develop & evaluate scenarios, such as reference levels of LWD or climate change predictions of water temperature
  - Working with unstandardized path coefficients
- Incorporate new variables
  - Predictors: stream temperature, restoration intensity, riparian condition, GCD as indicator of dynamic habitat
  - Responses: HSI, NREI, food web metrics derived from benthic macroinvertebrate data

Take home message

Useful products for managers-policy makers are *not* mutually exclusive with research on complex fish-habitat relationships.

This…. **Depends upon….** **This.**