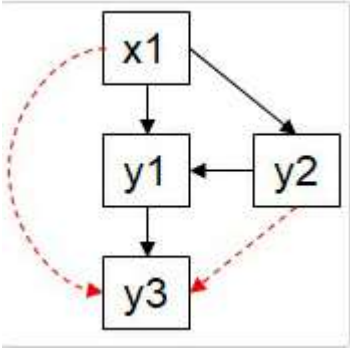
The advantages of piecewiseSEM ….

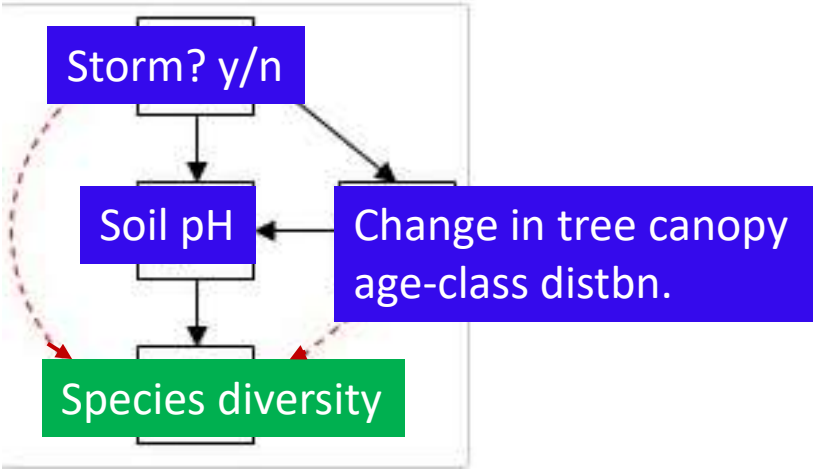
- Sit down quietly and construct a model where relationships are in series as well as in parallel and where these hypotheses reflect mechanisms and evidence at hand: black arrows below.



- The fit of your model is assessed against the missing paths: red arrows. In the jargon these are called ‘independence claims’.
- Previous methods did this by evaluating the whole model in one go (global estimation) but piecewiseSEM allows you to evaluate each model (local estimation) and then combine them. This is **REALLY** useful.

Applying expert knowledge before you start is critical…why?

- Because we are scientists!
- Avoids data-mining.
- This is not just a philosophical nicety. With only 4 variables there are 24 independence claims to test! (Shipley 2009. *Ecology* **90**, 363-368)
- Also *piecewiseSEM* will test any claims **not** hypothesised and so will tell you if you've missed any significant relationships.



Smart, et al (2014) *J.Ecol.* **102**, 1273-1287.

Explaining large-scale variation in a key soil quality indicator; Soil Aggregate Stability

Simon Smart[1], Matt Aitkenhead[2], Mark Cave[3], Gren Turner[3], Gaynor Barrett[1], Beverley Dodd[1], Rob Griffiths[1], Barry Rawlins[3], Aidan Keith[1]

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2 James Hutton Institute (JHI)

3 British Geological Survey (BGS)

SSP Soil Security Programme

CEH Centre for Ecology & Hydrology NATURAL ENVIRONMENT RESEARCH COUNCIL

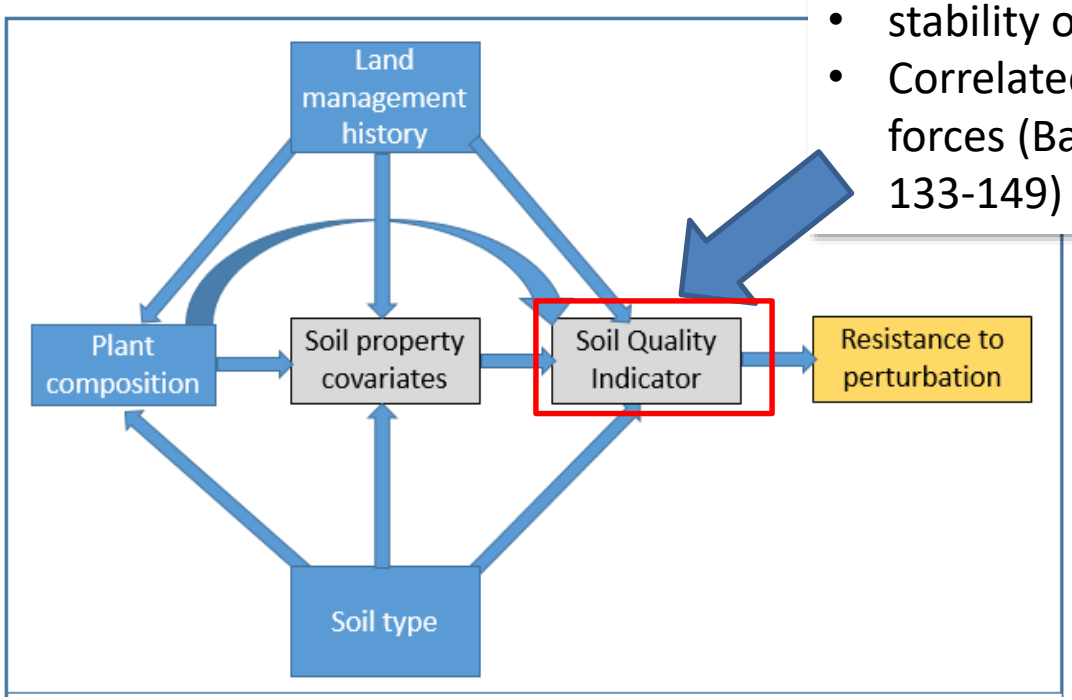
The James Hutton Institute

BGS 1835 British Geological Survey NATURAL ENVIRONMENT RESEARCH COUNCIL

OBJECTIVE

 # Identify key controls on soil quality indicators.

 # Why? So we can manage for greater soil resilience given demand for food, conservation of soil C, climate change, extreme weather, changes in crops and land-use



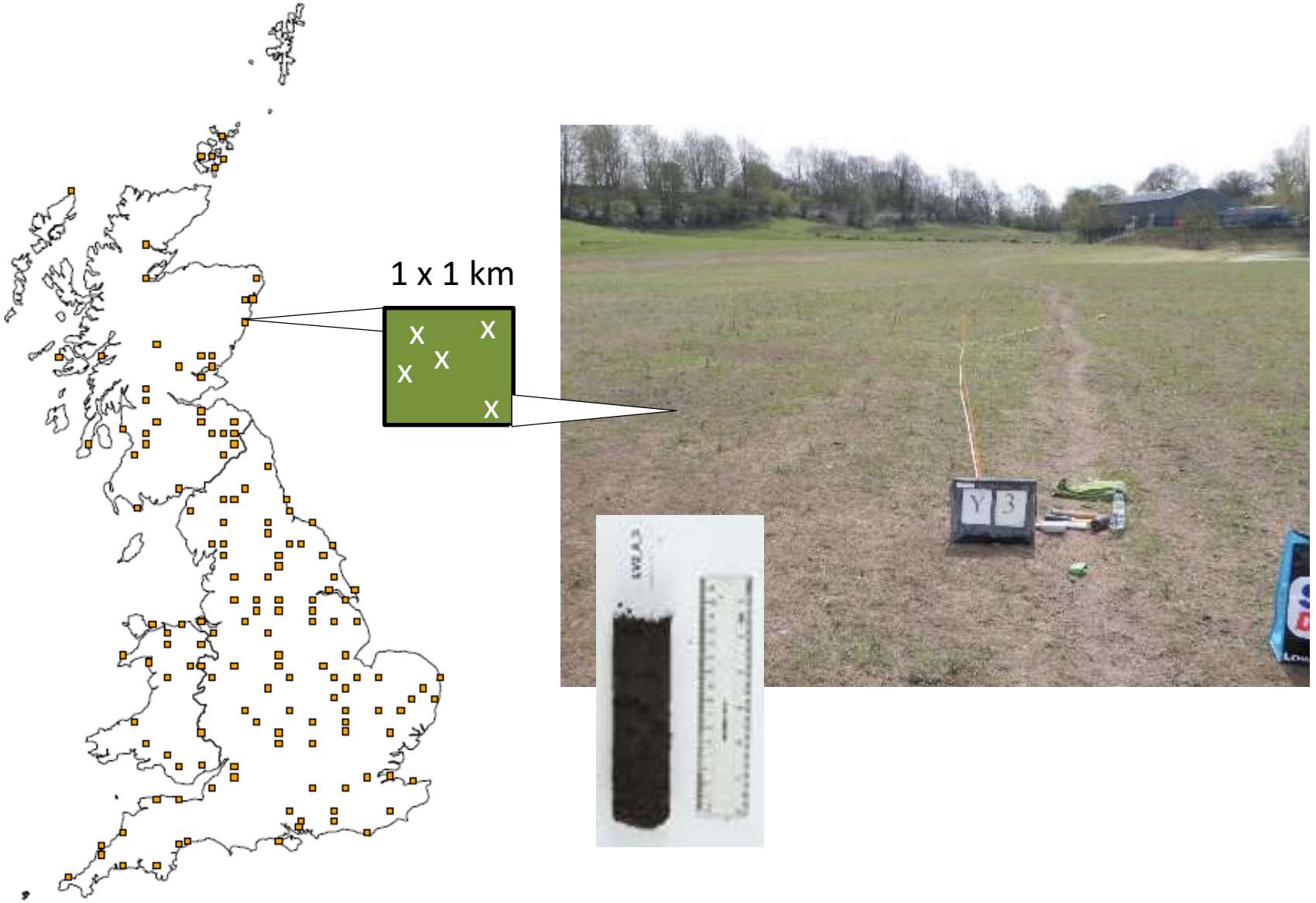
Soil Aggregate Stability

- stability of soil particles (<2mm diameter)
- Correlated with resistance to erosive forces (Barthès & Roose 2002 *Catena* **47**, 133-149)

"for every person on the planet an average 5 tonnes of soil are eroded every year" Quinton et al (2010) *Nature Geosci.* **3**, 311-314.

NATIONALLY REPRESENTATIVE SAMPLING DESIGN

#Vegetation (2x2m quadrat) and paired soil cores (5cm wide x 15cm deep) extracted from grassland and arable sampled by Countryside Survey in 2007 across Britain (n=286)



PLANT COMMUNITY & TRAIT-BASED PREDICTORS (2X2M QUADRAT):

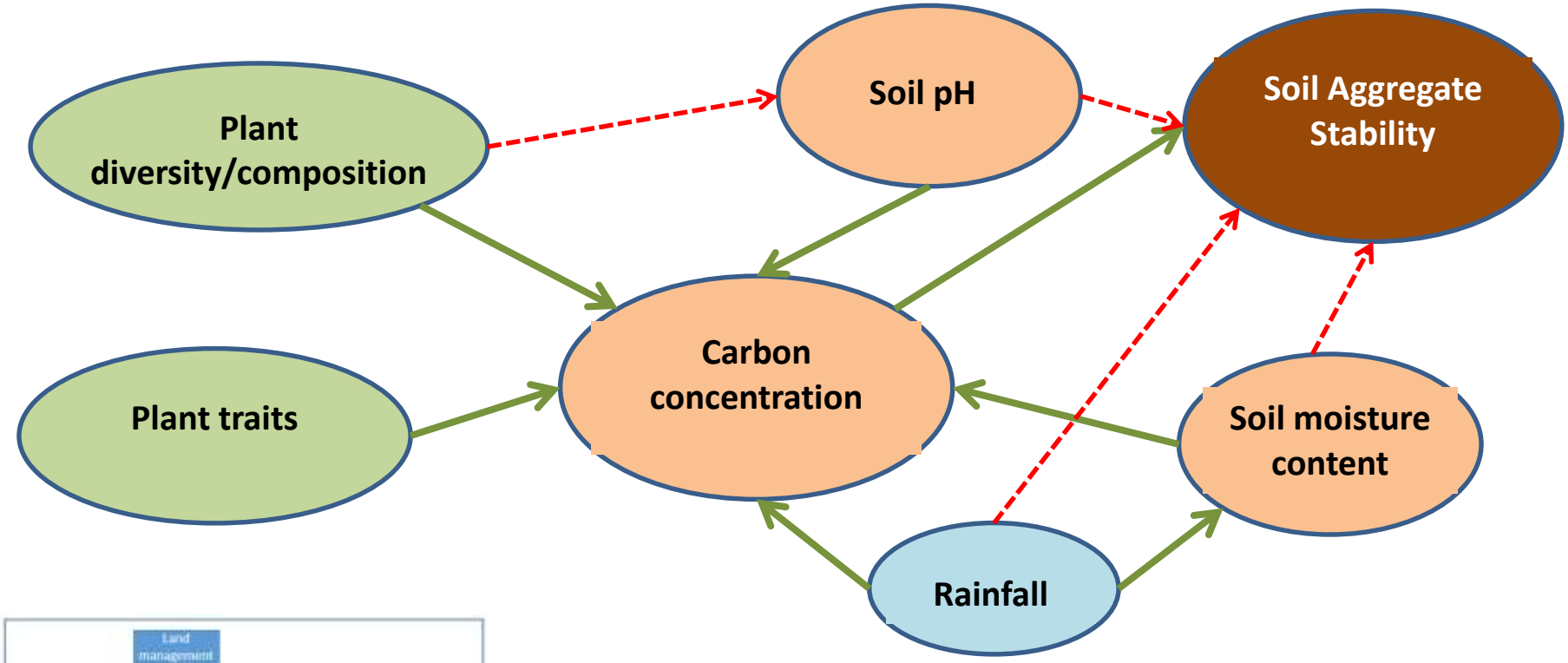
- **Grass:forb ratio**
- **Plant species richness**
- **Above-ground NPP** (g dry mass/m^2) – estimated from cover-weighted Leaf Dry Matter Content [1]; indicator of land-use intensity
- **Ordination (DCA) scores for vegetation axis 1**; strongly correlated with macronutrient availability [2,3]; indicator of land-use intensity
- **Specific Root Length** for dominant plant species extracted from FRED2.0 (m/g) [4]

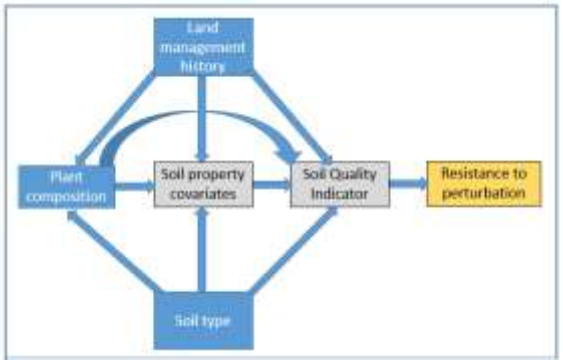
SOIL-DERIVED PREDICTORS (5X15CM CORE)[5]:

- **Carbon concentration** (g C/kg)
- **Volumetric soil moisture** (%)
- **Bulk density** (g/cm^3)
- **Soil pH** (fresh soil)

1. Smart et al 2017.*Funct.Ecol*. **31**, 1336-1344.
2. Rowe et al 2014. *Environ.Sci.Processes Impacts*. doi: 10.1039/c4em00312hHjh
3. Smart et al 2003. *J.Env.Man*. **67**, 239-254.
4. Iversen et al. 2018. *FRED v.2* https://doi.org/10.25581/ornlsfa.012/1417481
5. Emmett et al. 2007. *Countryside Survey. Soils Report from 2007*. www.countrysidesurvey.org.uk

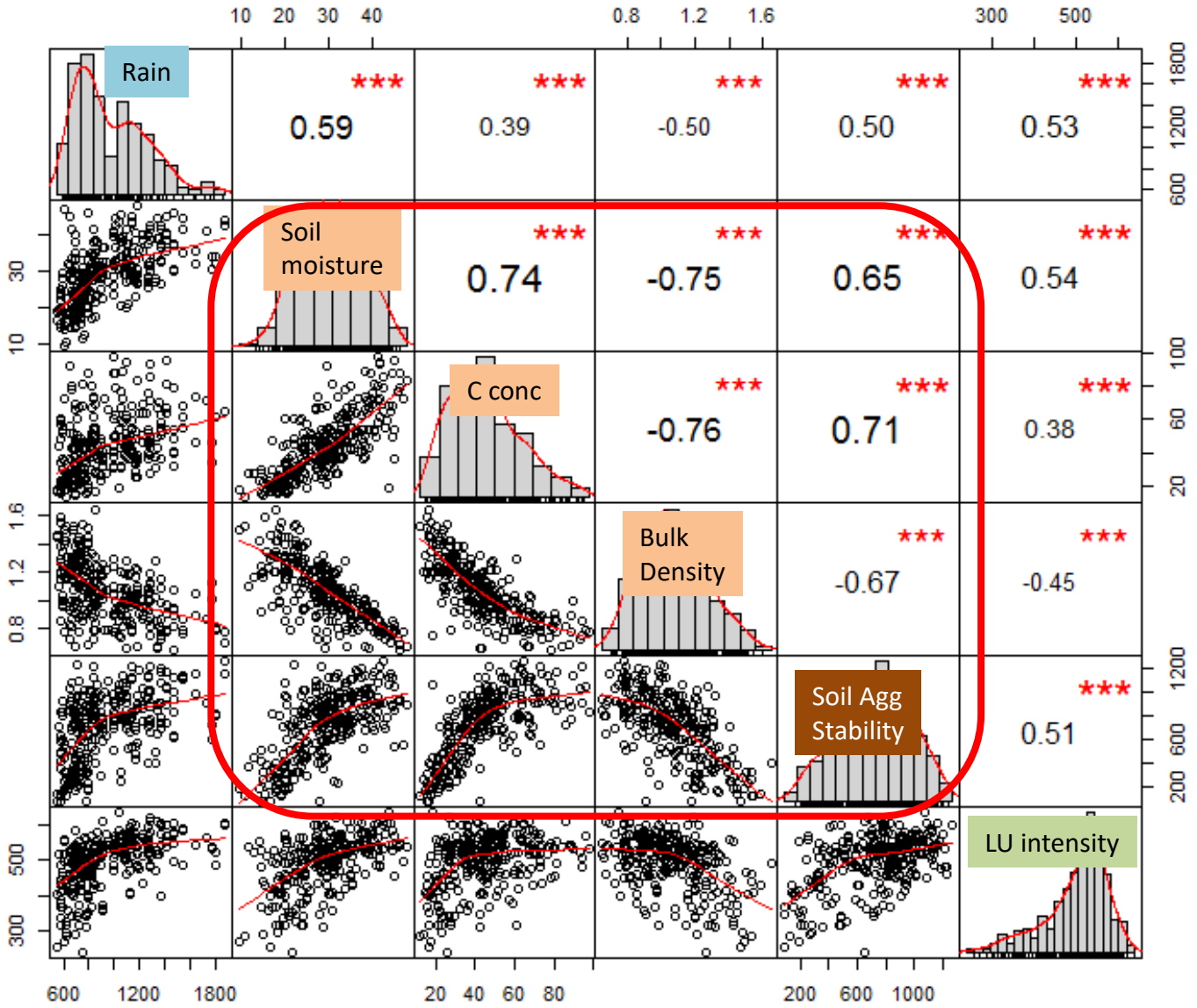
Plant traits, species composition, land-use intensity, soil pH, soil moisture and climate significant predictors of C fractions [1,2,3,4]. … many links are missing though!





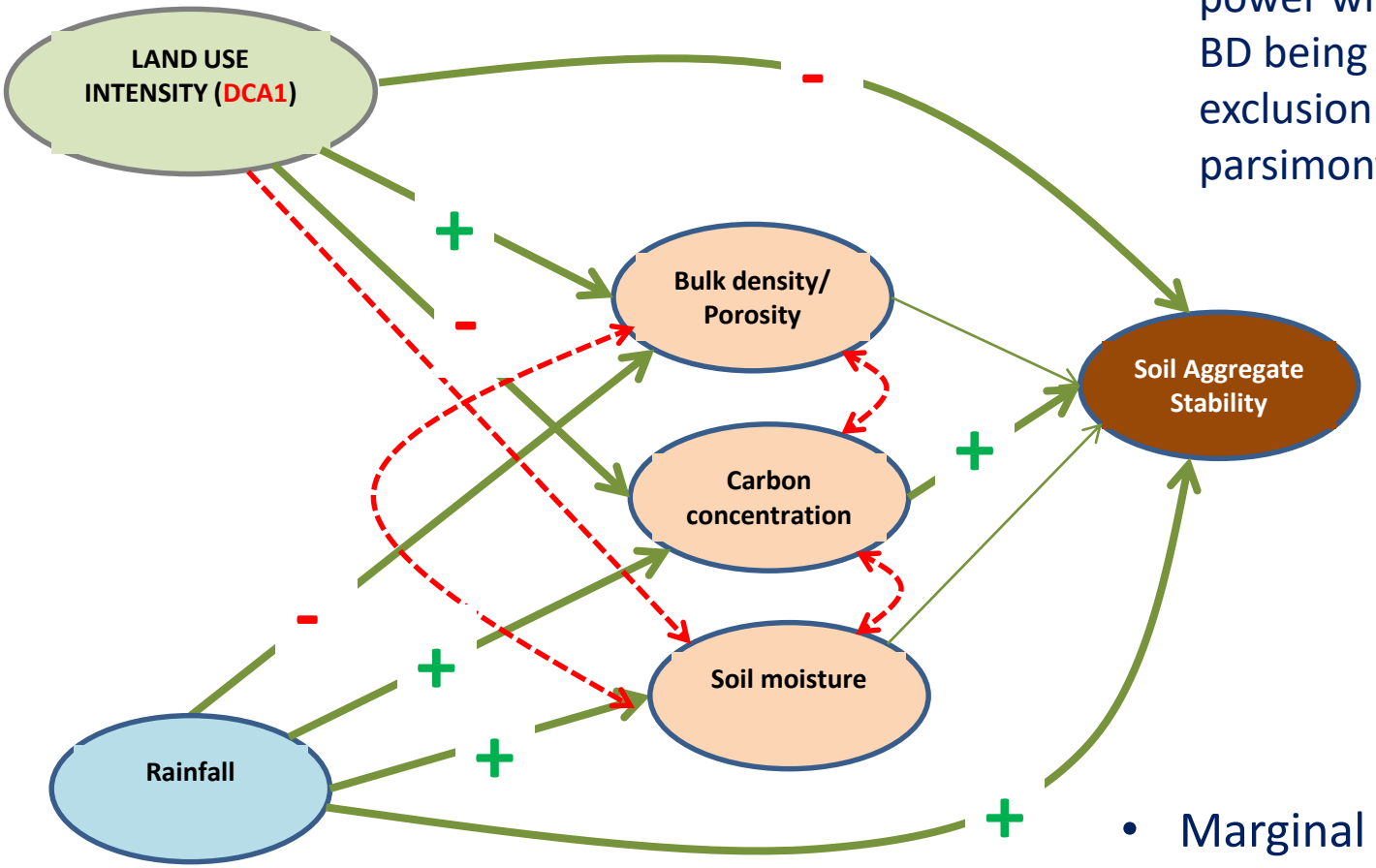
1. Wardle, DA et al 2012. *J.Ecol.* **100**, 16-30.
2. Manning, P et al 2015. *J.Appl.Ecol*. **52**, 1188-1196.
3. Ward, SE et al 2016. *Glob.Change.Biol.* **22**, 2929–2938.
4. Laliberté, E et al. 2012. *Ecology* **93**, 144-155.

Results 1. Which minimum set of covariates explained most variation given our hypotheses? (lmer, car::anova, OutlierTest, LR test)



#Model 1: AIC = 480, P = 0

- Basis set includes highly correlated soil variables.
- They differ in explanatory power with soil moisture then BD being candidates for exclusion on grounds of parsimony.

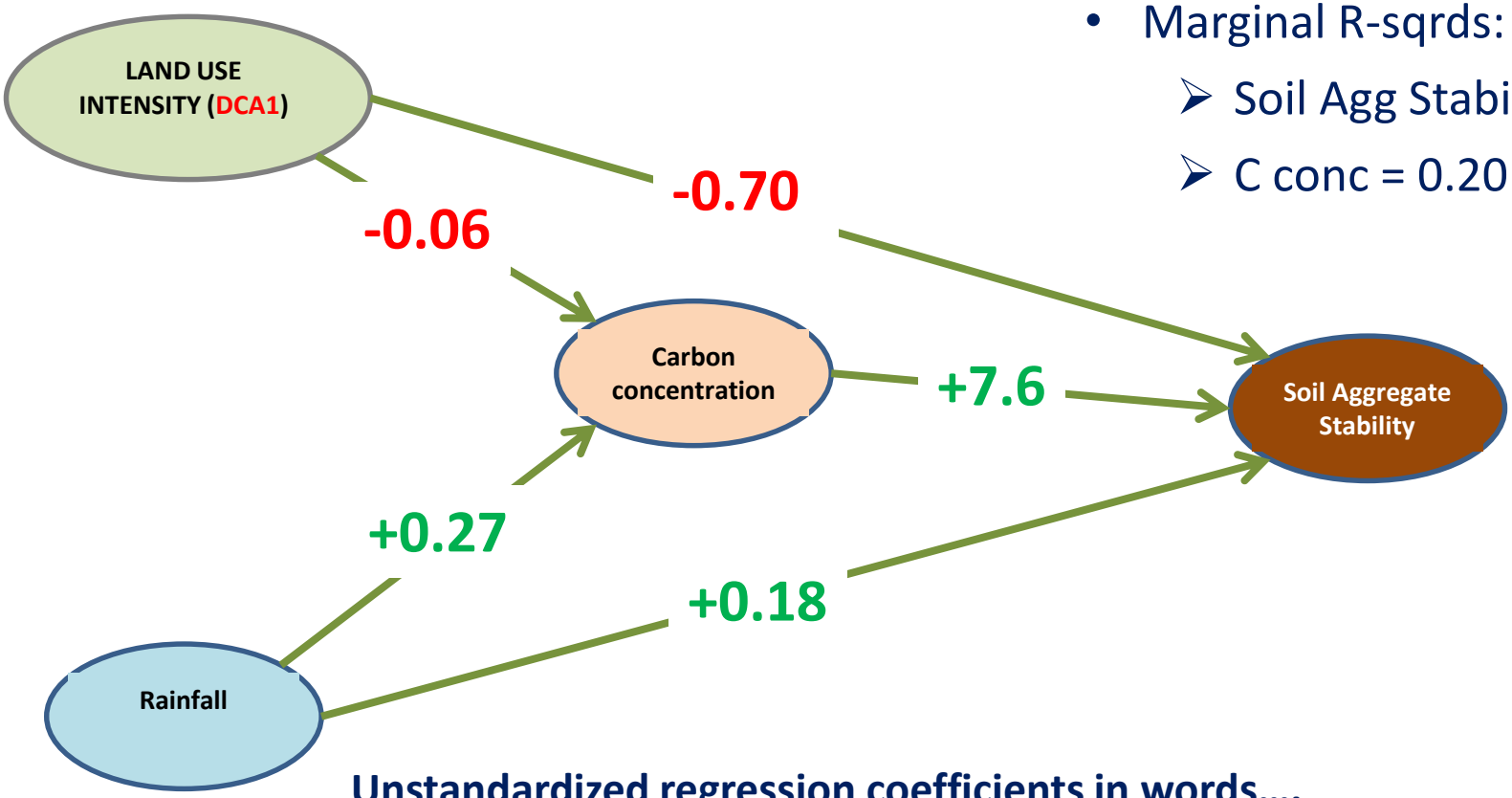


- Marginal R-sqrds:
  - Soil Agg Stability = 0.55
  - C conc = 0.20

"Blindly selecting all the significant tests and re-inserting those paths, however, is irresponsible and in fact antithetical to the philosophy of SEM (*where paths are carefully specified by the user*)." **J.Lefchek**

#Model 4: AIC = 22. The best model.

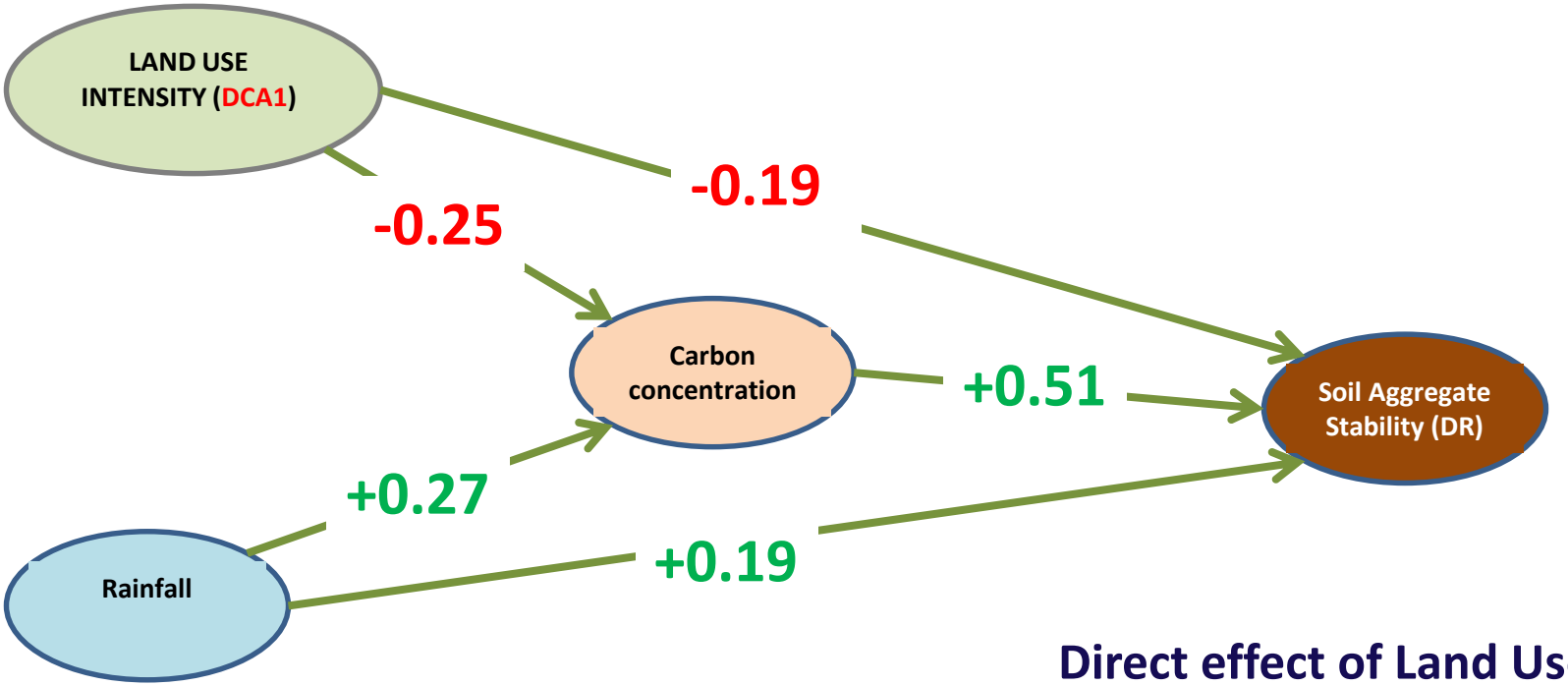
- **It's simple at least!**
- Marginal R-sqrds:
  - Soil Agg Stability = 0.54
  - C conc = 0.20



Unstandardized regression coefficients in words….

- An increase of 1 g C/kg **increases** Soil Agg Stability by 7.6 µm.
- An increased 10 mm of rainfall **increases** Soil Agg Stability by 1.8 µm.
- A 1% increase in land-use intensity **decreases** C concentration by 0.24 g C/kg and directly **decreases** Soil Agg Stability by 2.8 µm.

Getting more information from the output: effect sizes (mean / sdev) …. What would es=1 mean?



Cohen (1988) suggested that d=0.2 be considered a 'small' **effect size**, 0.5 represents a 'medium' **effect size** and 0.8 a 'large' **effect size**. This **means** that if two groups' **means** don't differ by 0.2 standard deviations or more, the difference is trivial, even if it is statistically signficant.

Direct effect of Land Use on DR?

-0.19

Indirect effect of Land Use on DR?

-0.25 * 0.51 = -0.13

Total effect of Land Use on DR?

(-0.25 * 0.51) + -0.19 = -0.318

Sources of information on *piecewiseSEM*

- https://github.com/jslefche/piecewiseSEM
- https://jslefche.github.io/sem_book/index.html
- piecewiseSEM R package (Lefchek 2016 *Methods in Ecol. Evol.* **7**, 573-579)
- Jon Lefchek answers email queries especially since the package is evolving and he's keen to improve it/hear about issues.
- Check out the package *blavaan* though. Bayesian SEM combining *lavaan* and *Stan* or *JAGS*.