Structural equation models

Montana Chapter of The Wildlife Society

4 March 2024

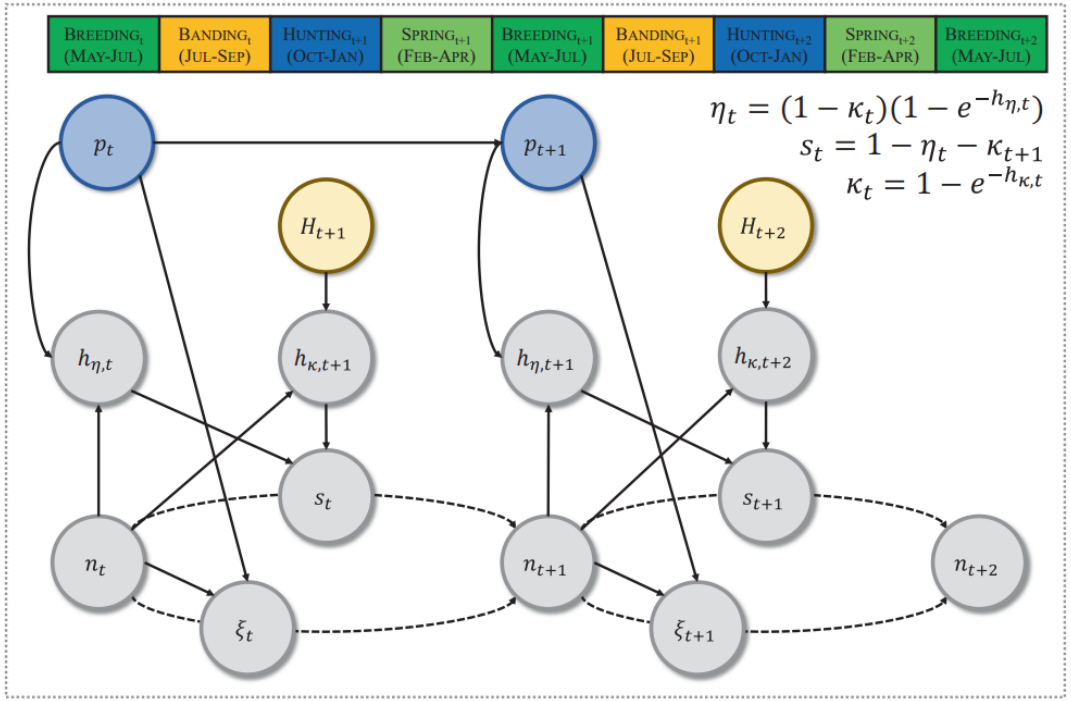


FIGURE 2 A directed acyclic graph demonstrating the relationships among abundance (***n***), ponds (***p***; blue), fecundity (ξ), hunting mortality hazard rate ($\boldsymbol{h}_\kappa$), natural mortality hazard rate ($\boldsymbol{h}_\eta$), survival (**s**) and the number of duck hunters (***H***; brown) for blue-winged teal breeding in the North American Prairie Pothole Region across the annual cycle (1973–3016). Solid arrows represent estimated directional relationships, and dashed arrows represent processes leading to changes in population abundance.

Facilitators!

Colton Padilla

Kaitlyn Vega

Sunny Domschot

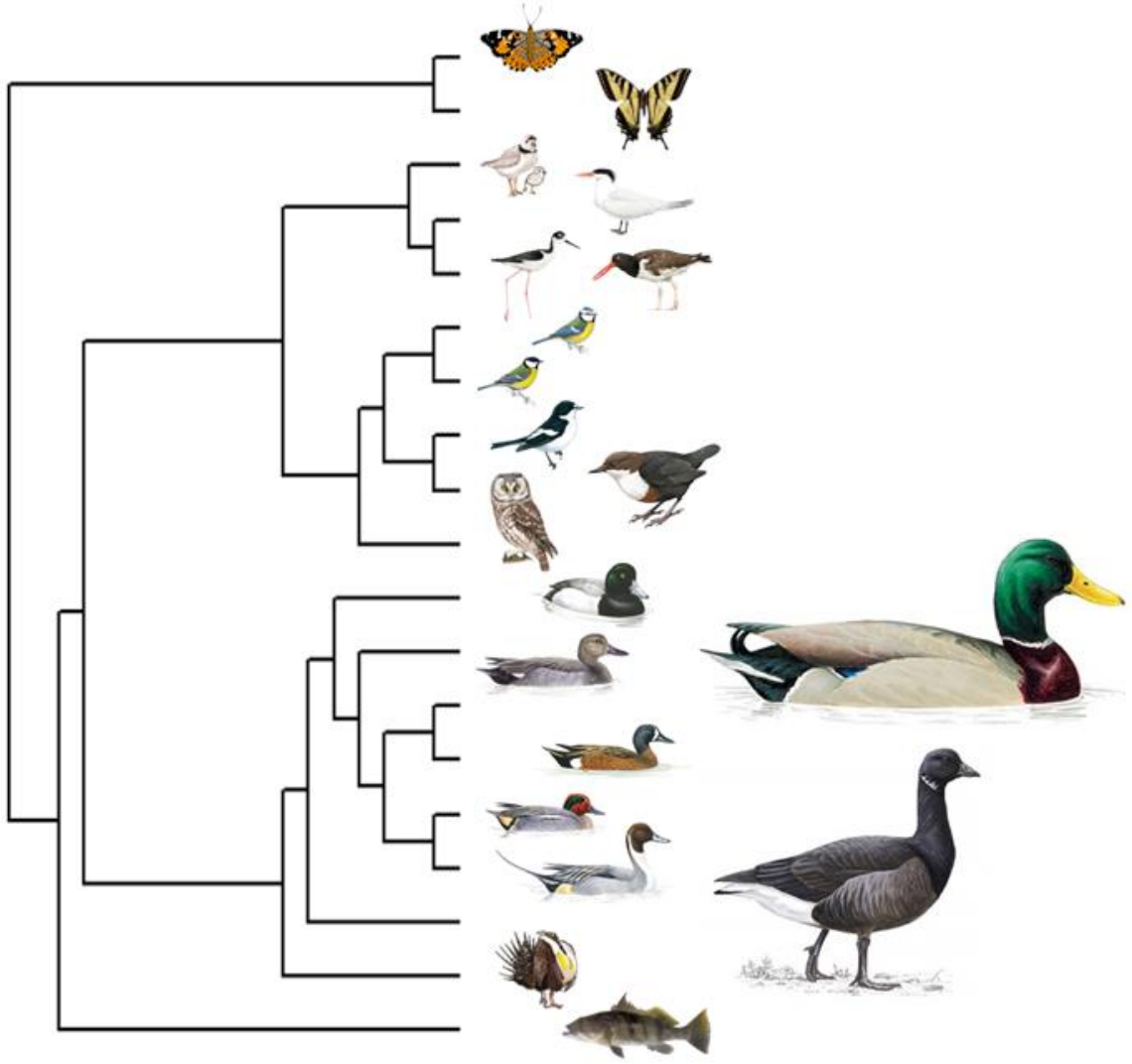
Liv Lundin

Hi!

Thomas Riecke

Assistant Professor

James K. Ringelman Chair in Waterfowl Conservation



thomas.riecke@umontana.edu

What is structural equation modeling, and why is it useful?

Time	Topic
	Theory (mostly talking, little bit of doing)
0900-0945	Why are we doing this?
1000-1045	Linear models to path analysis
1100-1145	Latent variables
	Application (mostly doing, little bit of talking)
1300-1345	Path analysis work session
1400-1445	SEM work session
1500-	Cross-lags, Bayes implementations, and questions

Learning outcomes or goals

- Demonstrate why these techniques are useful and important!
- Direct you towards useful reading and learning opportunities.
- Put you in the ‘driver’s seat’ for some basic and perhaps not-so-basic analyses

Quick notes and ‘tone’

- This is ‘take one’ for a one-day workshop!
  - Currently it’s a semester-long Bayesian SEM course.
  - It will eventually be a one-week Bayes/SEM workshop, and maybe a book.
- Feedback is **very** welcome!
- There are no ‘bad’ questions!

SEMs often feel overwhelming?!

Special Section: Observational Studies

Structural Equation Modeling for Observational Studies

JAMES B. GRACE,[1] *United States Geological Survey National Wetlands Research Center, 700 Cajundome Boulevard, Lafayette, LA 70506, USA*

$$y_1 = \alpha_1 + \gamma_{11}x_1 + \zeta_1 \quad (1)$$

$$y_2 = \alpha_2 + \gamma_{21}x_1 + \gamma_{22}x_2 + \beta_{21}y_1 + \zeta_2 \quad (2)$$

$$y_3 = \alpha_3 + \gamma_{31}x_1 + \gamma_{32}x_2 + \beta_{31}y_1 + \beta_{32}y_2 + \zeta_3 \quad (3)$$

Simplifying the LISREL system for the case where there are no latent variables and ignoring the intercept terms, a generalized representation of a system of such equations is

$$Y = BY + \Gamma X + \zeta \quad (4)$$

Grace et al. **(2008)** *Journal of Wildlife Management*

Everything is overwhelming if we don’t know the language

1) Put the **Taulov** on the **Golv**

2) Arrange four **Stefans** on the **Taulov**

3) Put the **Krokig** between the **Stefans**

4) Put the **Nattjasmin** over the **Stefans** and **Krokig**

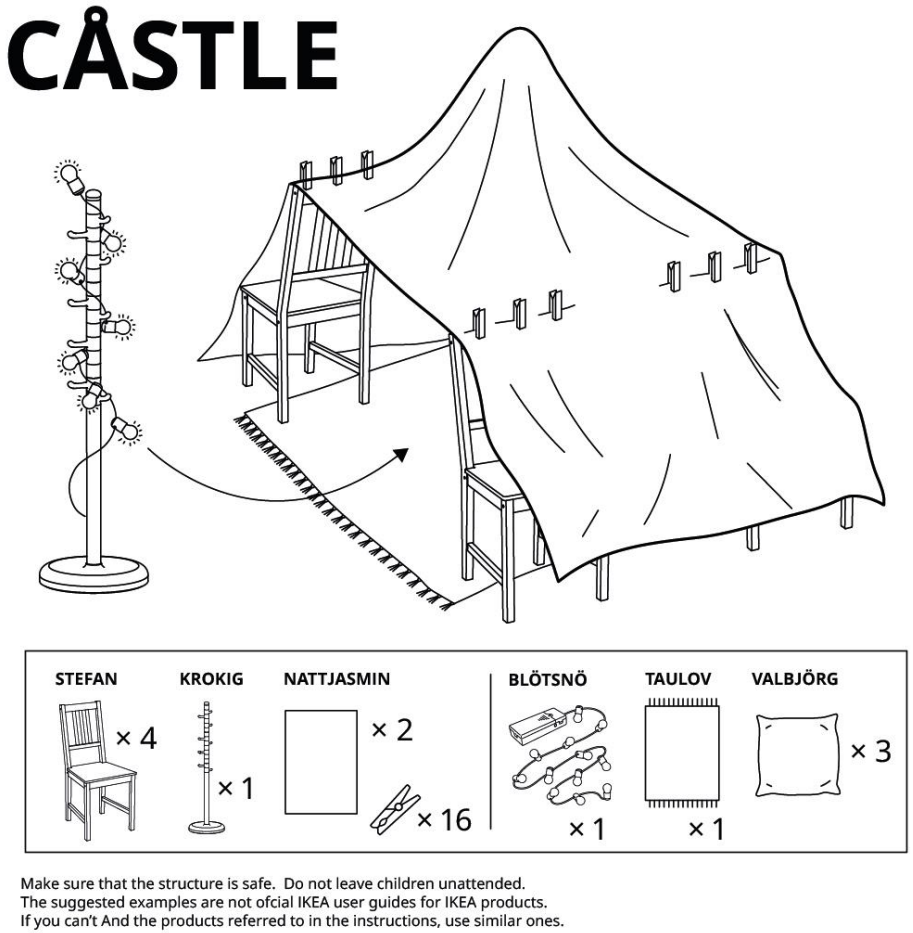
Everything is overwhelming if we don’t know the language

1) Put the **rug** on the **floor**

2) Arrange four **chairs** on the **rug**

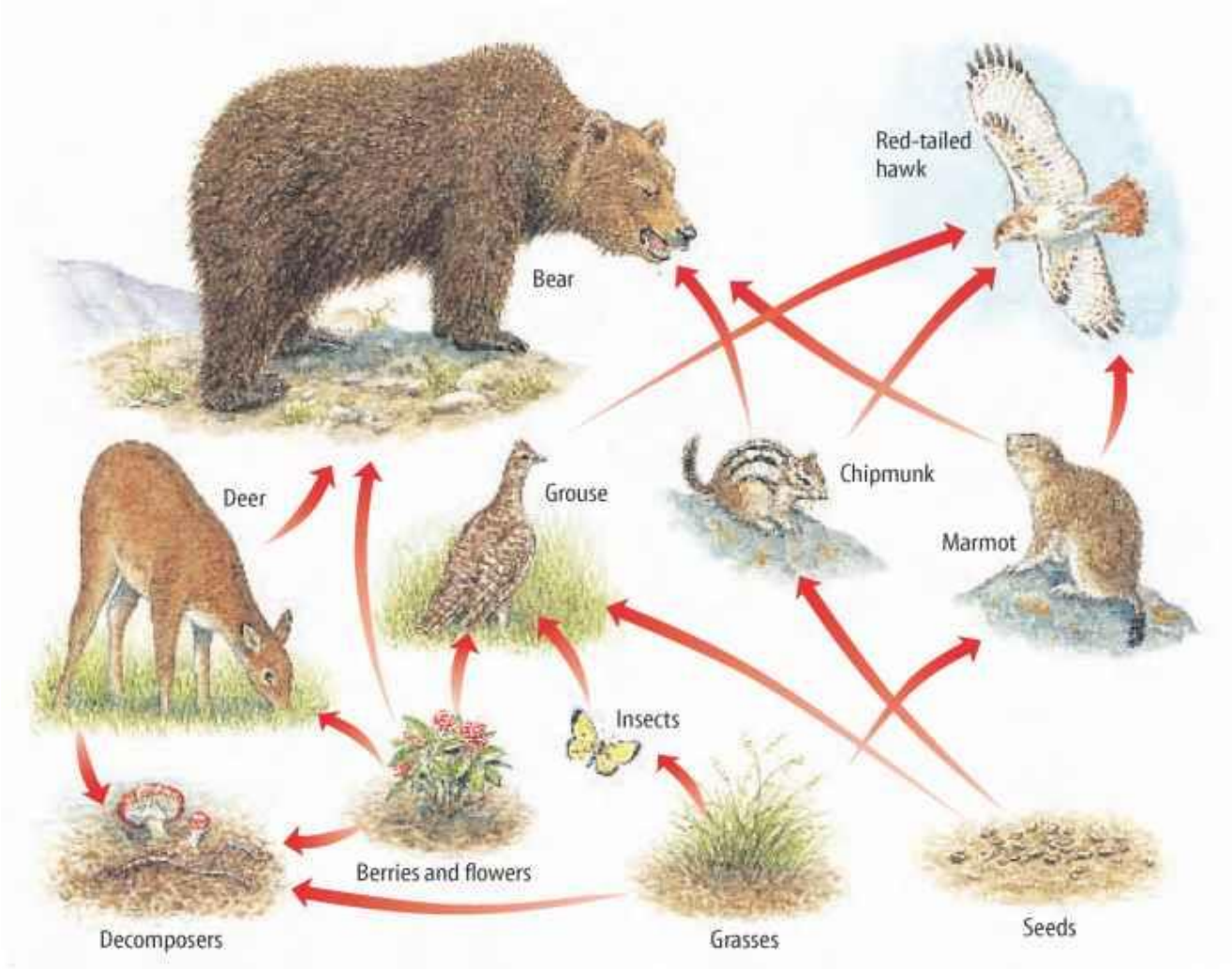
3) Put the **lamp** between the **chairs**

4) Put the **blanket** over the **chairs** and **lamp**



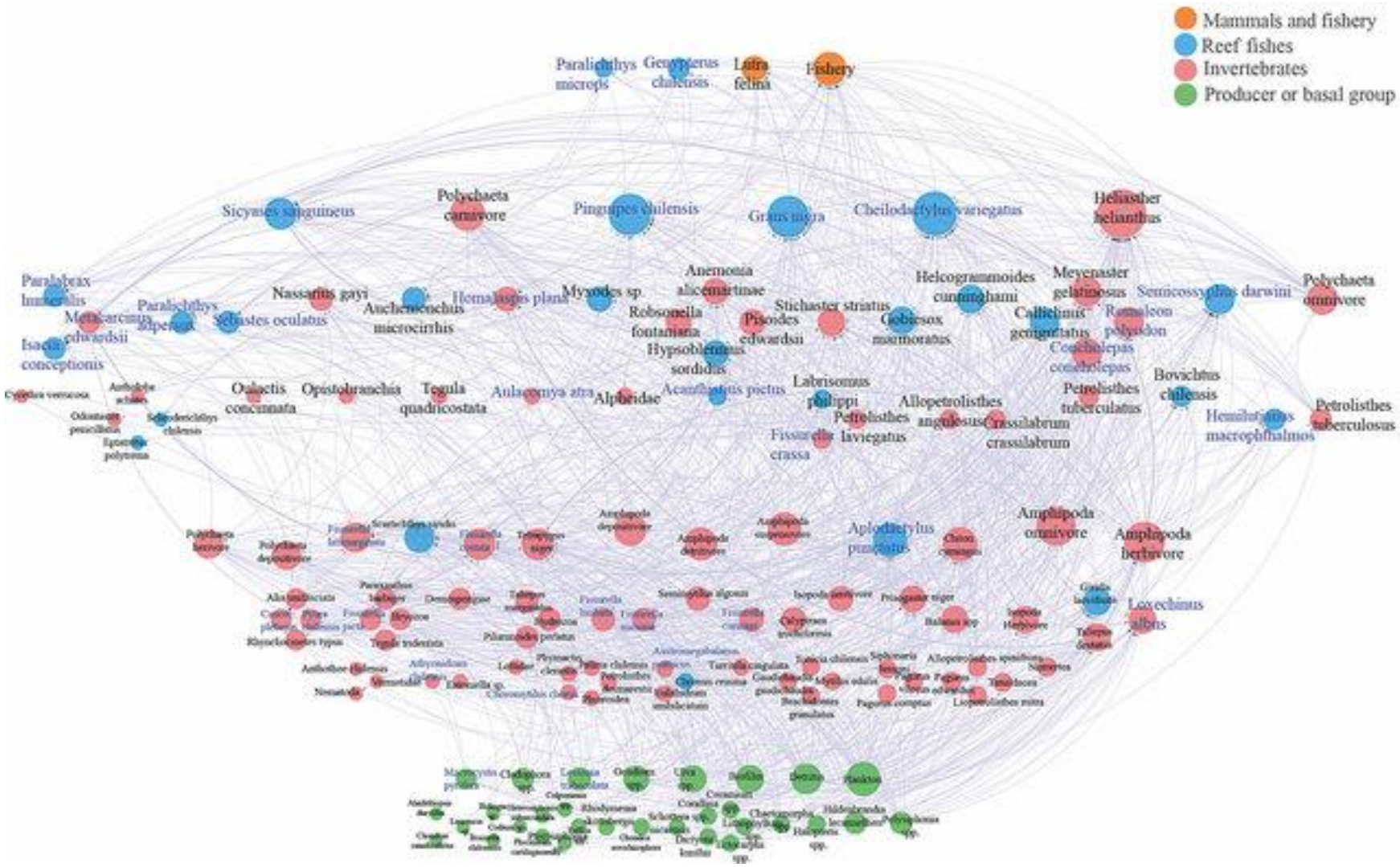
Why are we doing this?

Ecological systems are complex networks (e.g., food webs)



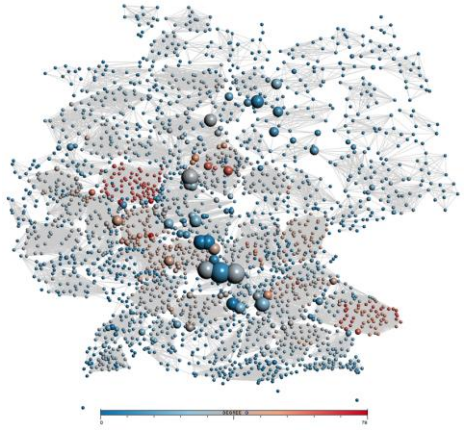
Your elementary school biology textbook (probably)

Ecological systems are complex networks (e.g., food webs)



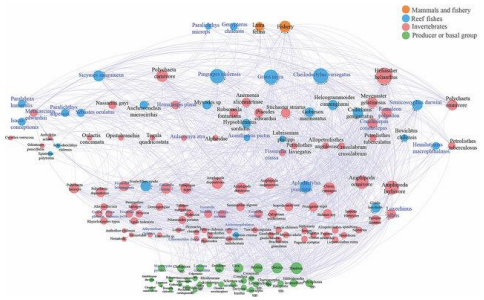
Perez-Matus et al. (2017) Marine Ecology Progress Series

Ecological systems are <u>unbelievably</u> complex networks…



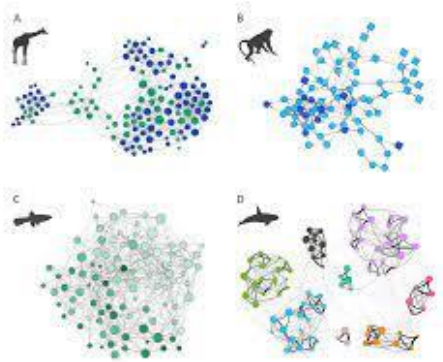
Climate network
Abiotic systems

Tominski et al. (2017)
Information Visualization IV



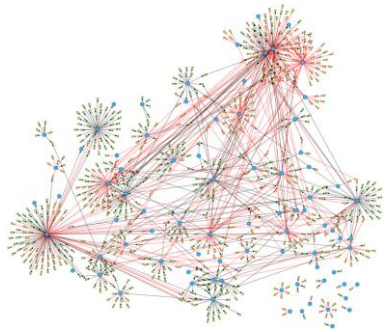
Food Network
Among populations

Perez-Matus et al. (2017)
Marine Ecology Progress Series



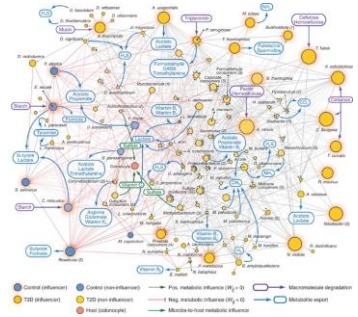
Social Network
Within populations

Brask et al. (2005)
arXiv



Gene Network
Within individuals

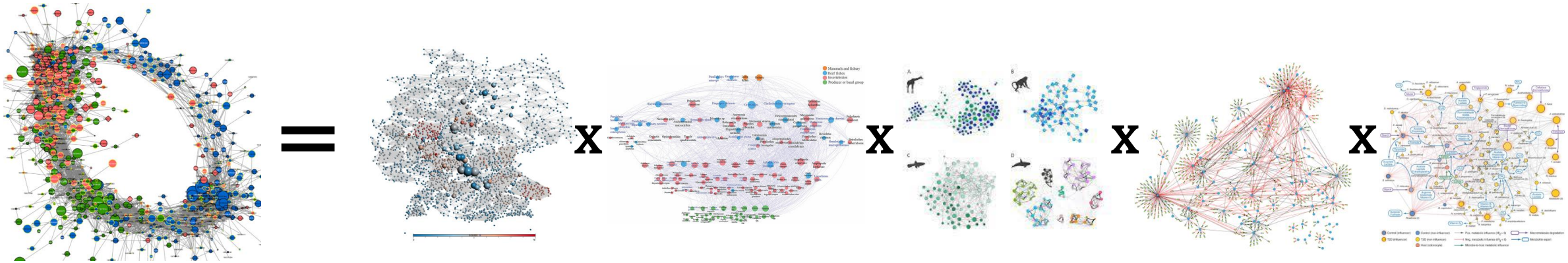
Ma et al. (201)
PLOS ONE



Microbial Network
Within individuals

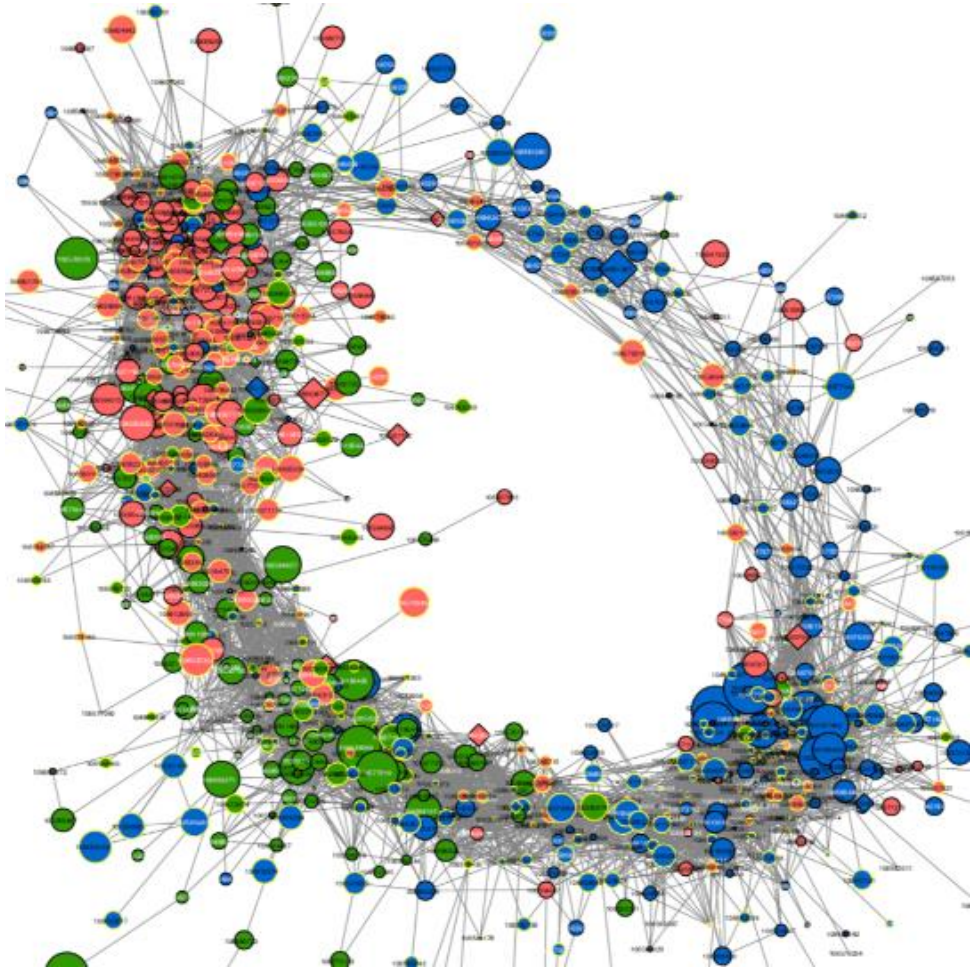
Sung et al. (2017)
Nature Communications

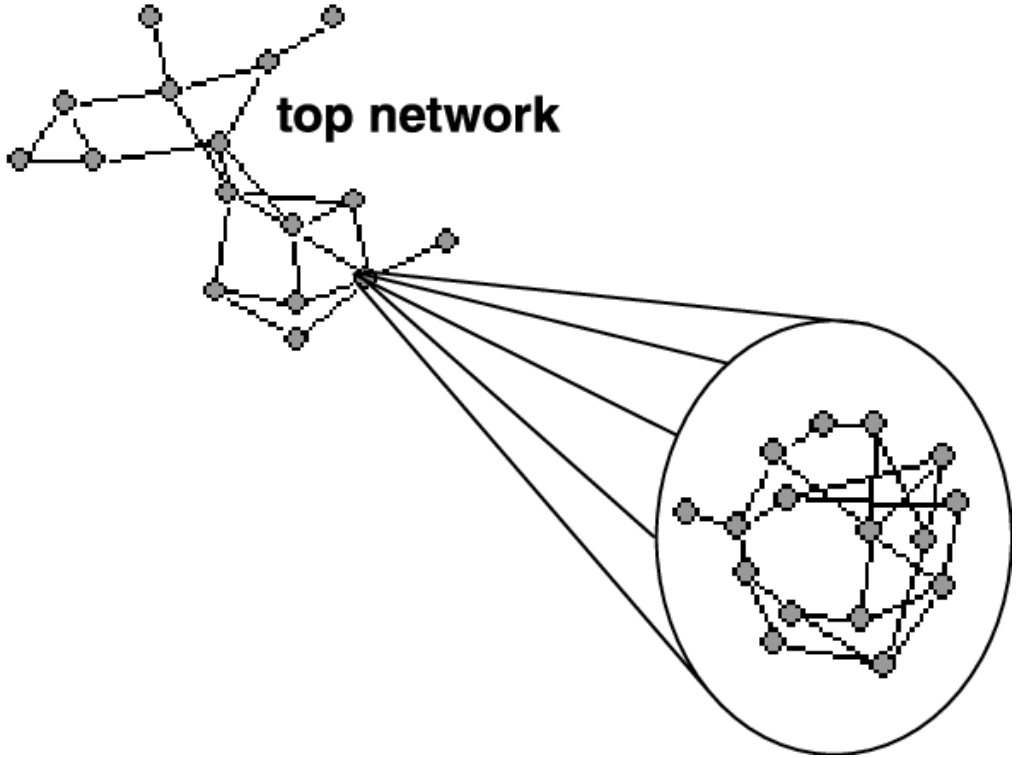
‘Ecological reality’ is a complex product of abiotic conditions, community, population & social dynamics, genetics, & microbial communities



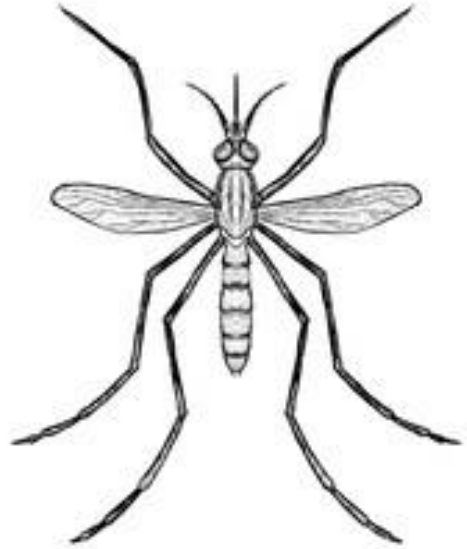
‘Reality’

Ecological reality is <u>beyond our comprehension</u>





Ecological reality is <u>beyond our comprehension</u> (ECOL/EVST 101)



We’re taught this over and over again (e.g., Operation Cat Drop)

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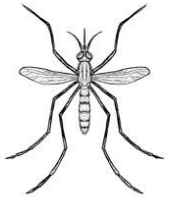
Parachuting Cats into Borneo – A Cautionary Tale

In the early 1950’s, the Dayak people of Borneo suffered a malarial outbreak. The World Health Organisation (WHO) had a solution: to spray large amounts of DDT to kill the mosquitoes that carried the malaria. The mosquitoes died; the malaria declined; so far so good. But there were unexpected side effects. Amongst the first was that the roofs of the people’s houses began to fall down on their heads. It seemed that the DDT had also killed a parasitic wasp which had previously controlled thatch-eating caterpillars. Worse, the DDT-poisoned insects were eaten by geckoes, which were eaten by cats. The cats started to die, the rats flourished, and the people were threatened by outbreaks of typhus and plague. To cope with these problems, which it had itself created, the WHO was obliged to parachute 14 000 live cats into Borneo. Operation Cat Drop, now almost forgotten at the WHO, is a graphic illustration of the interconnectedness of life, and of the fact that the root of problems often stems from their purported solutions.

(Quoted in Rachel Wynberg and Christine Jardine, *Biotechnology and Biodiversity: Key Policy Issues for South Africa,* 2000)

DDT



No more malaria

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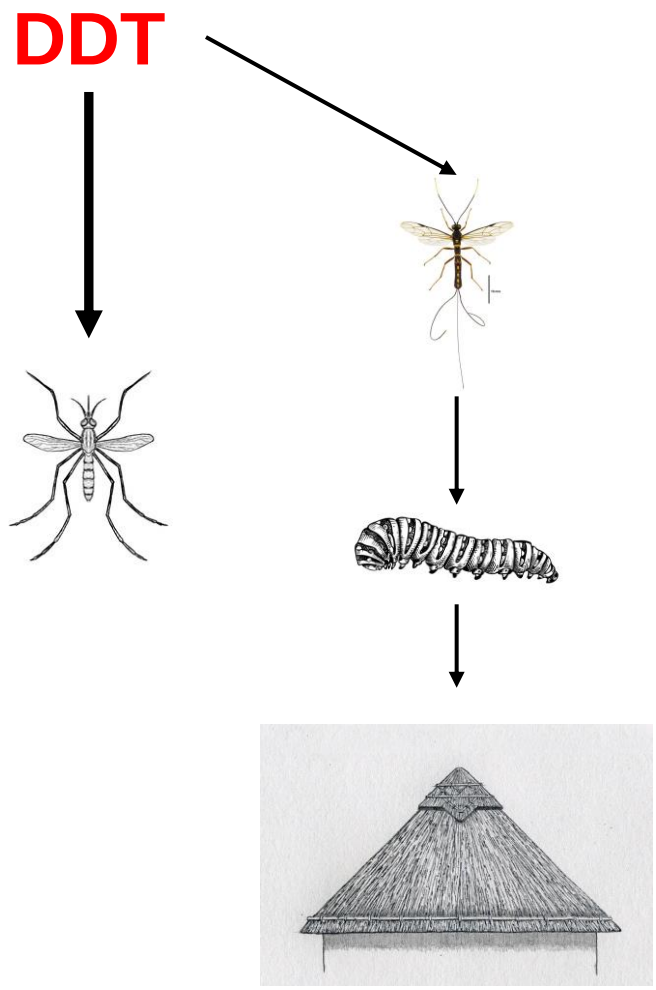

<u>No more malaria, but roofs collapsing</u>

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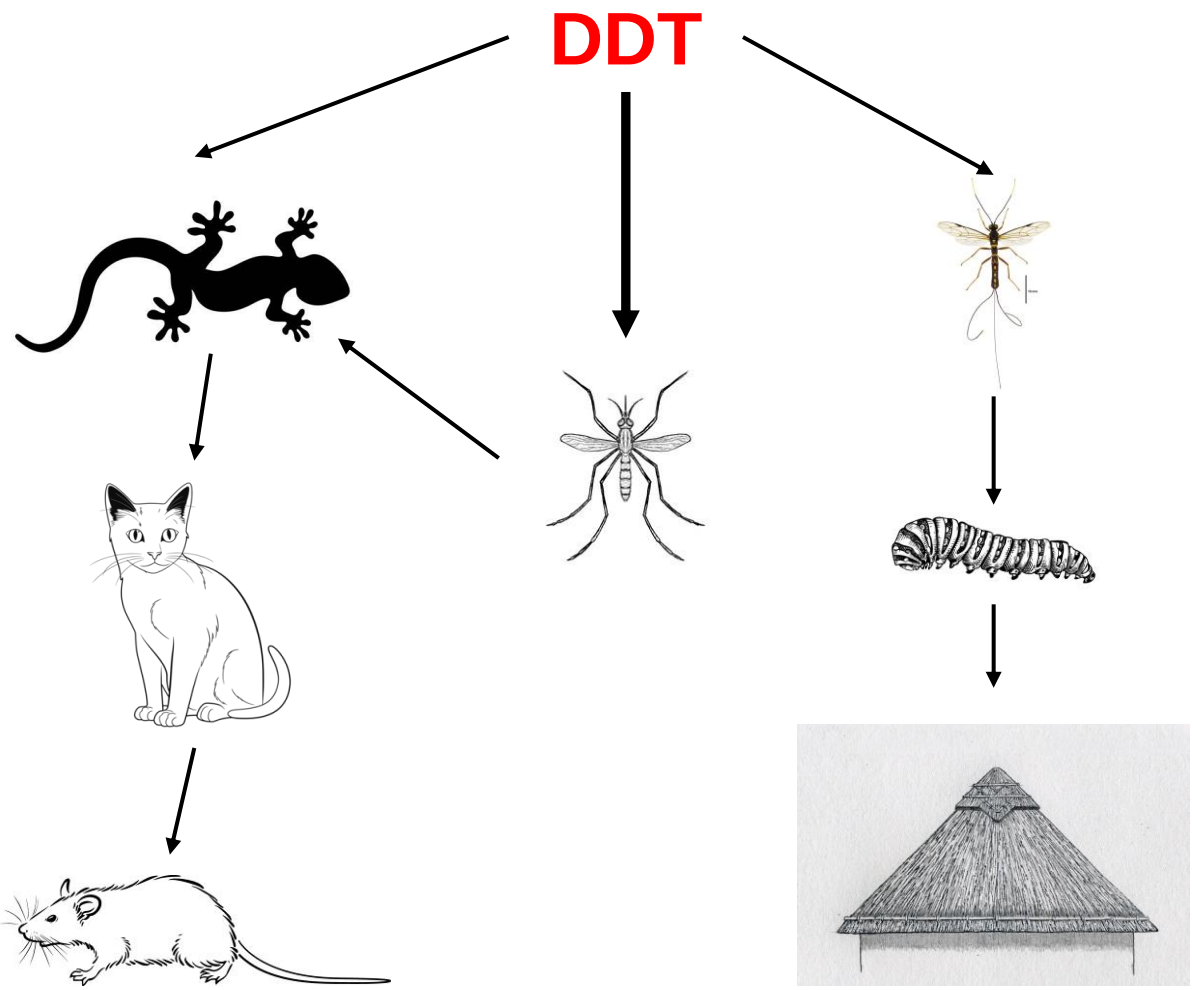
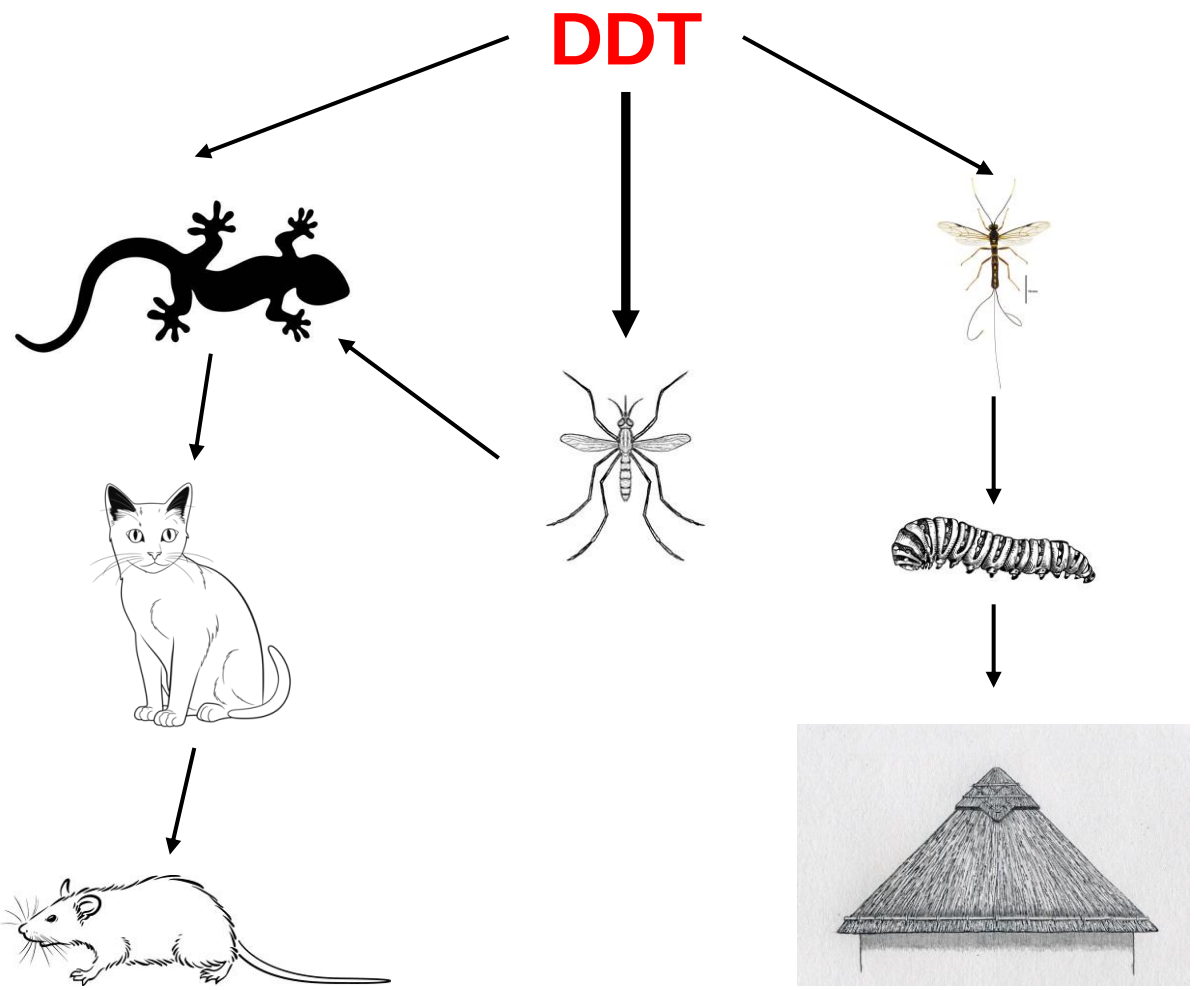


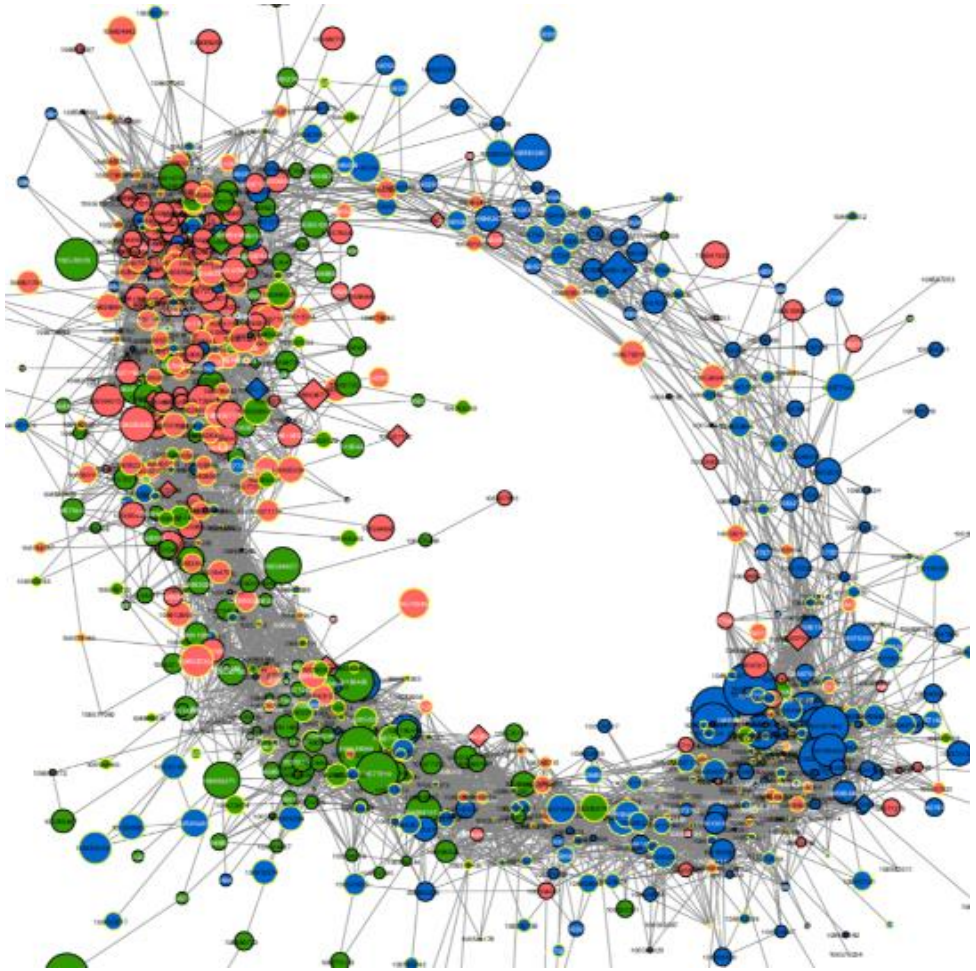
<u>No more malaria, but roofs collapsing, plague and typhus spreading</u>

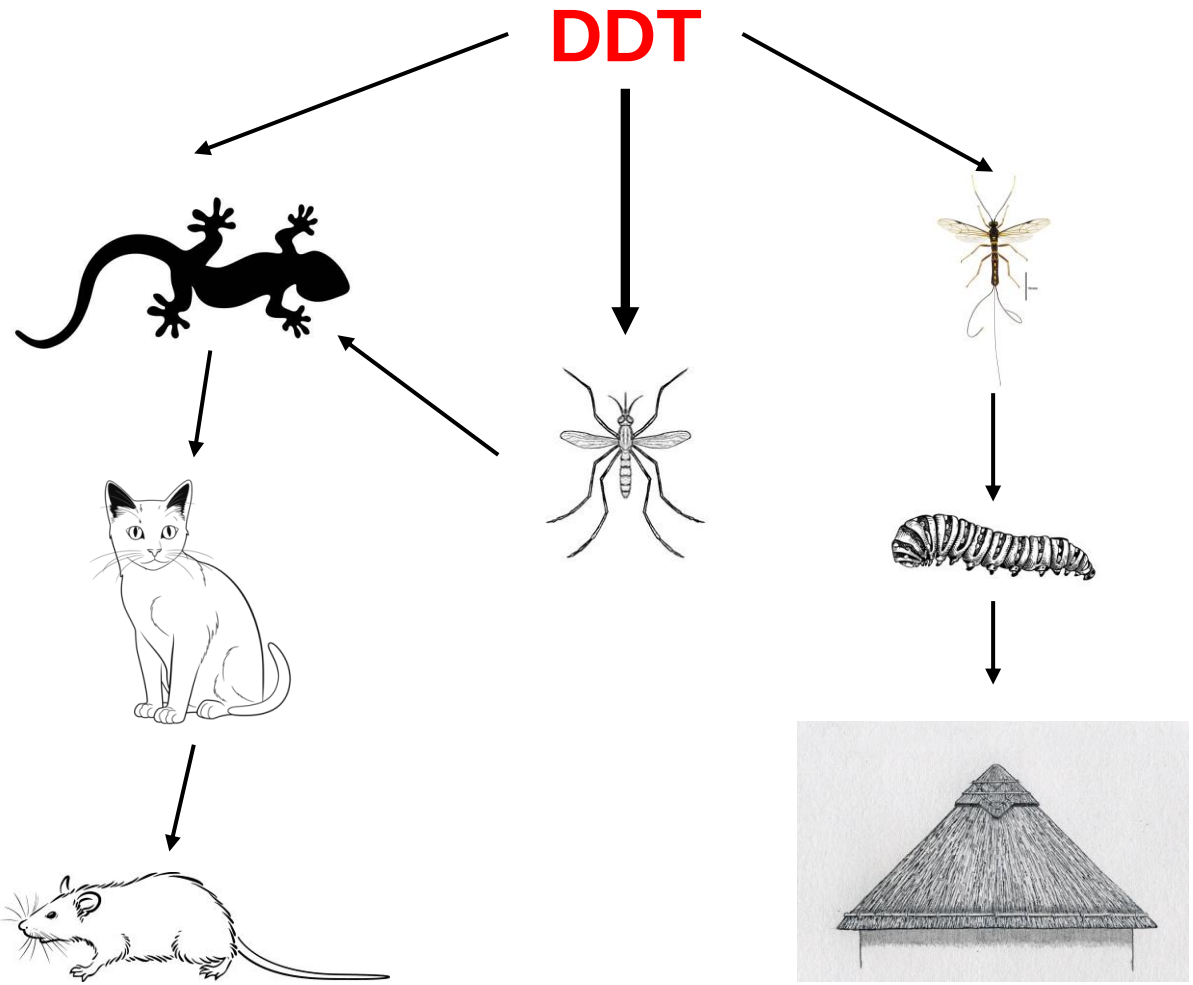
We’re taught this over and over again (e.g., Operation Cat Drop)



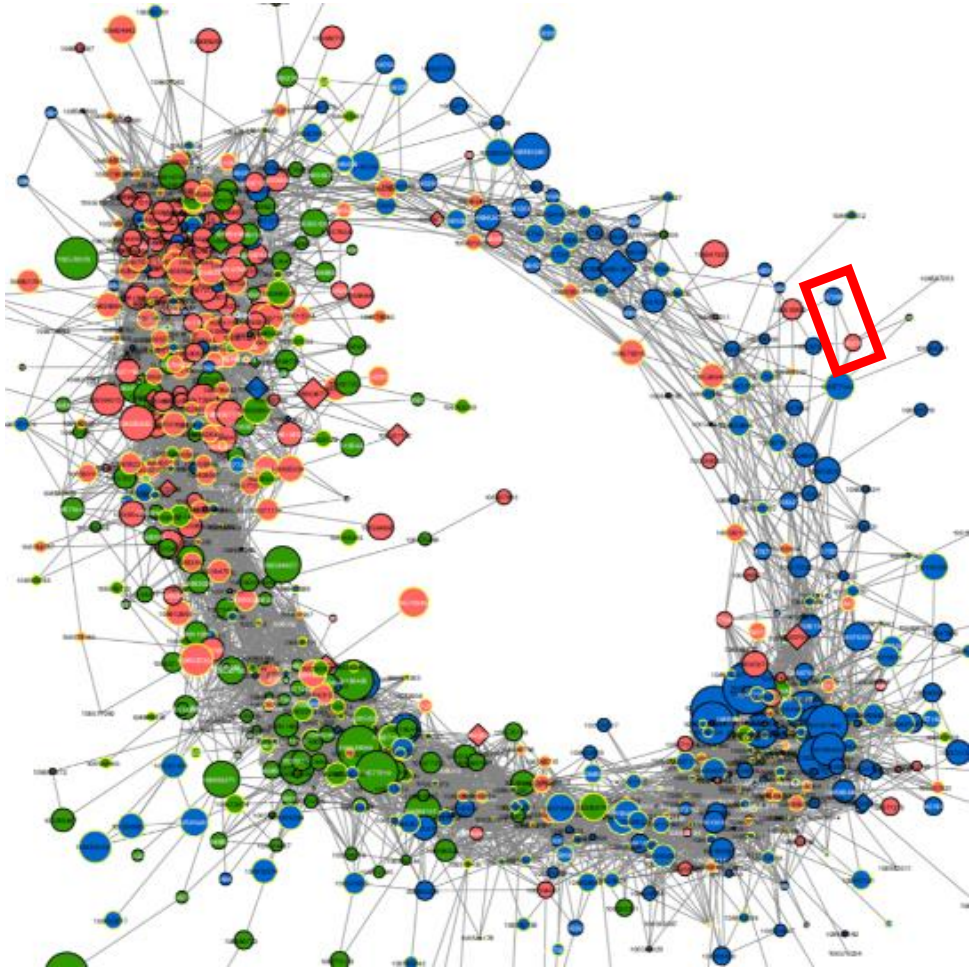
No more malaria, but roofs collapsing, plague and typhus spreading, so RAF air-dropped 14k cats

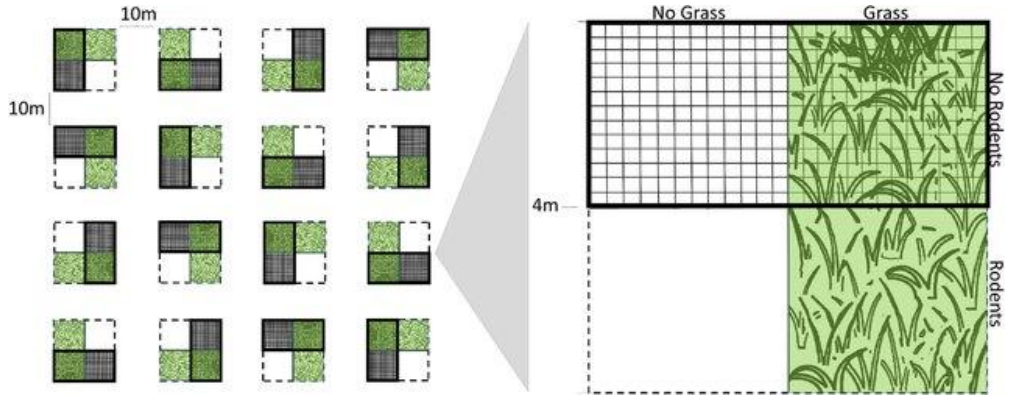
Complexity strikes again!





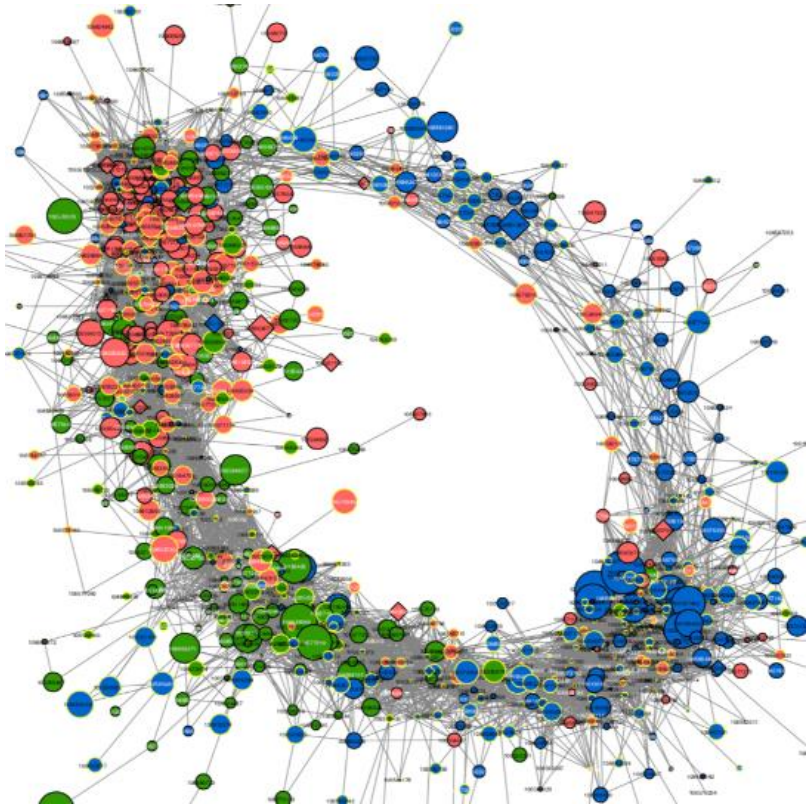
Science responds to this complexity with experiments





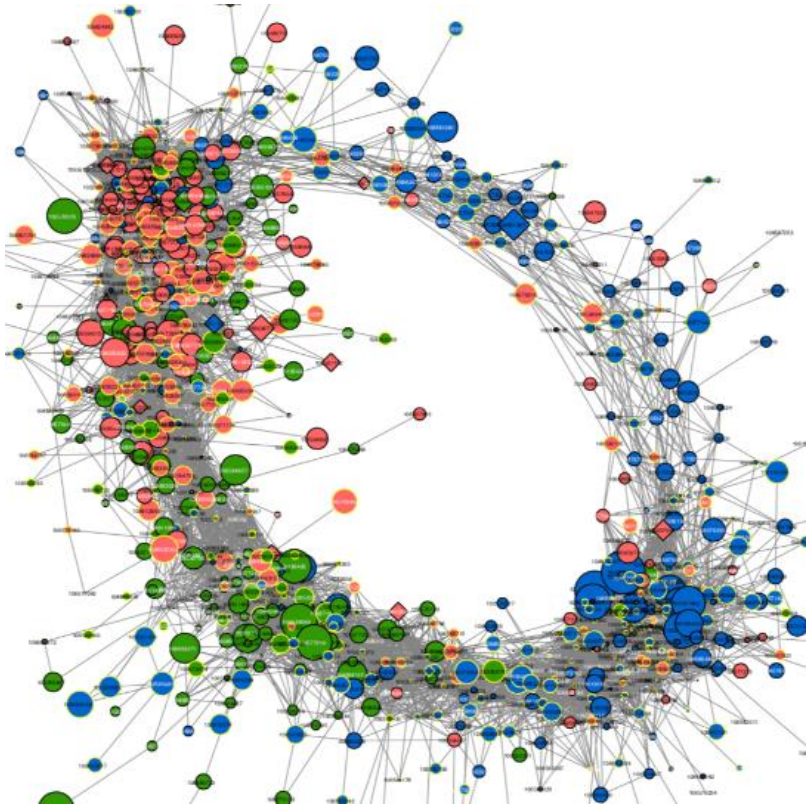
Experiments are often <u>beautiful</u>!

We can’t always do experiments (for myriad reasons)



Similar problems in other fields (e.g., epidemiology, social sciences)

We can never do experiments in the past!

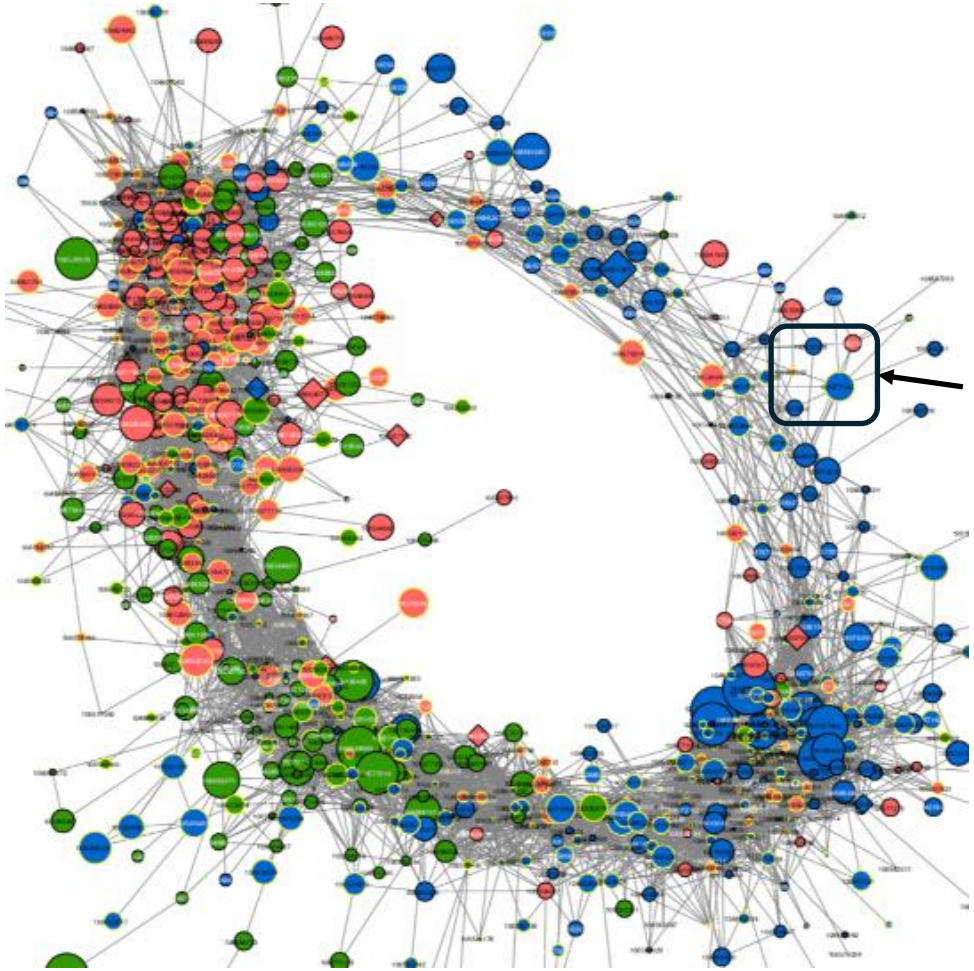


Similar problems in other fields (e.g., epidemiology, social sciences)

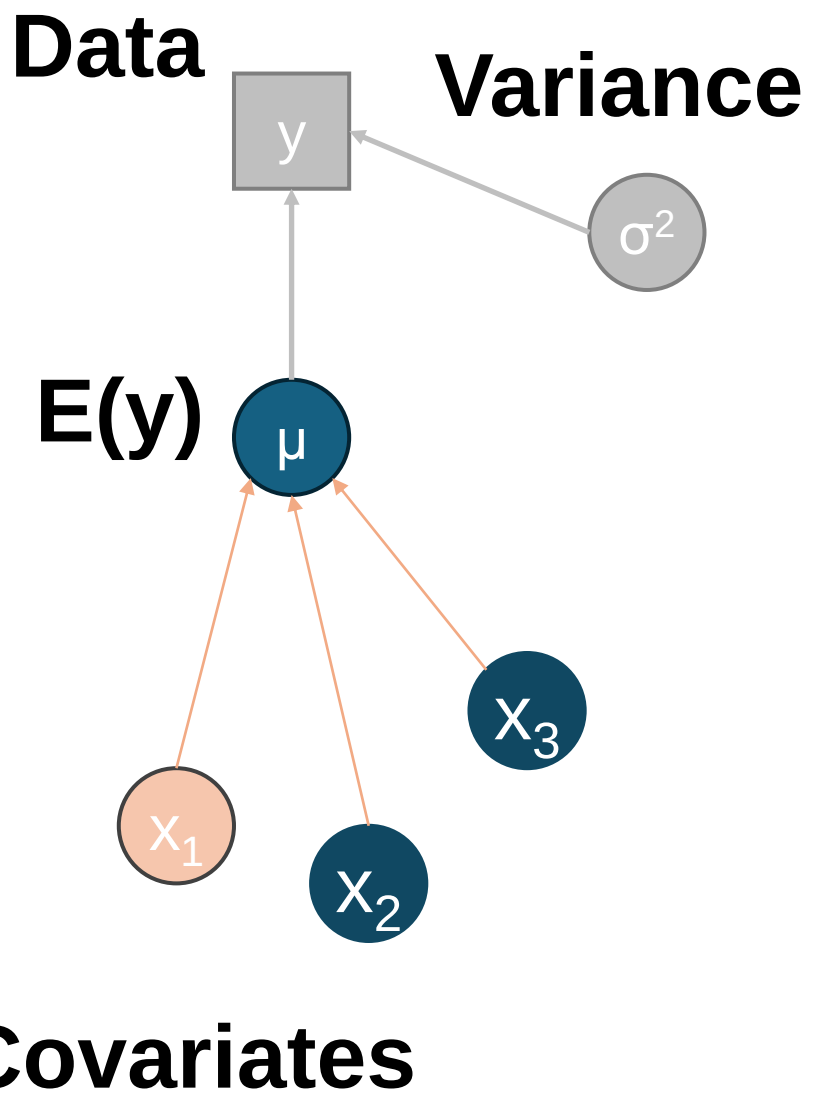
Darn it!

So what do we do?!

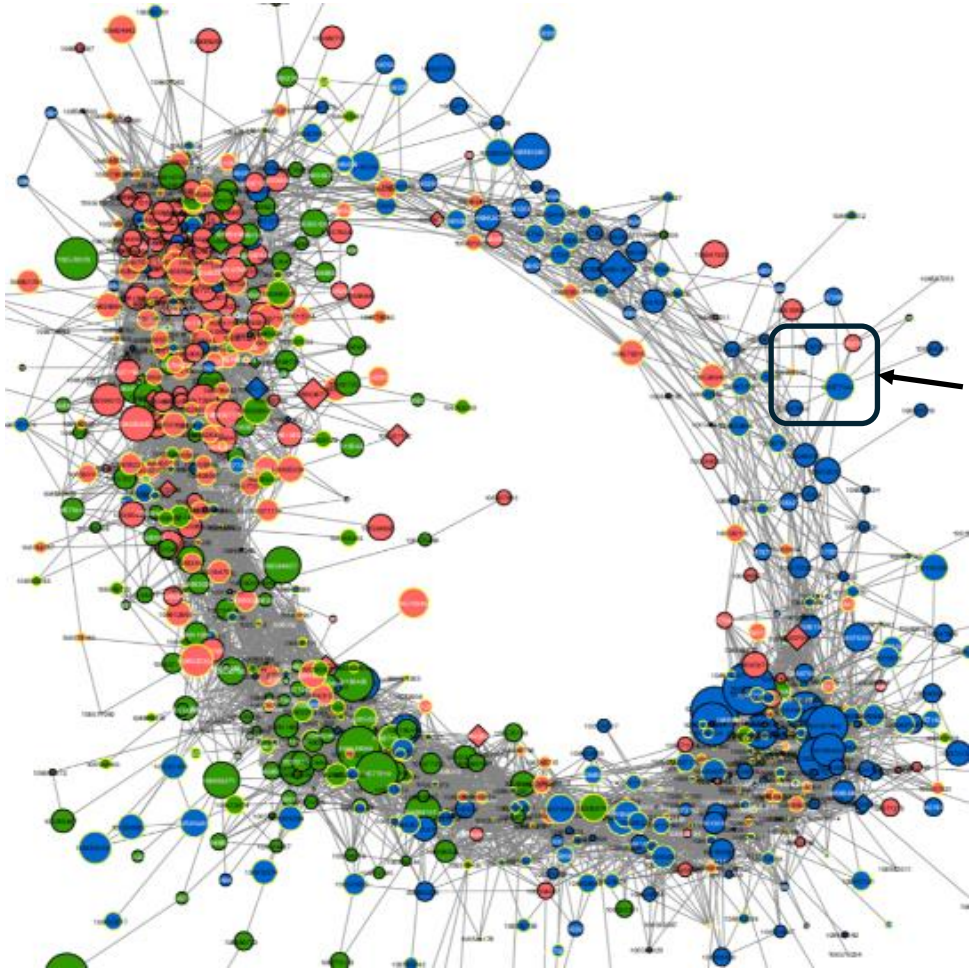
GLMs dominate observational ecological analyses



We collect data here



GLMs focus on a single response as a function of covariates



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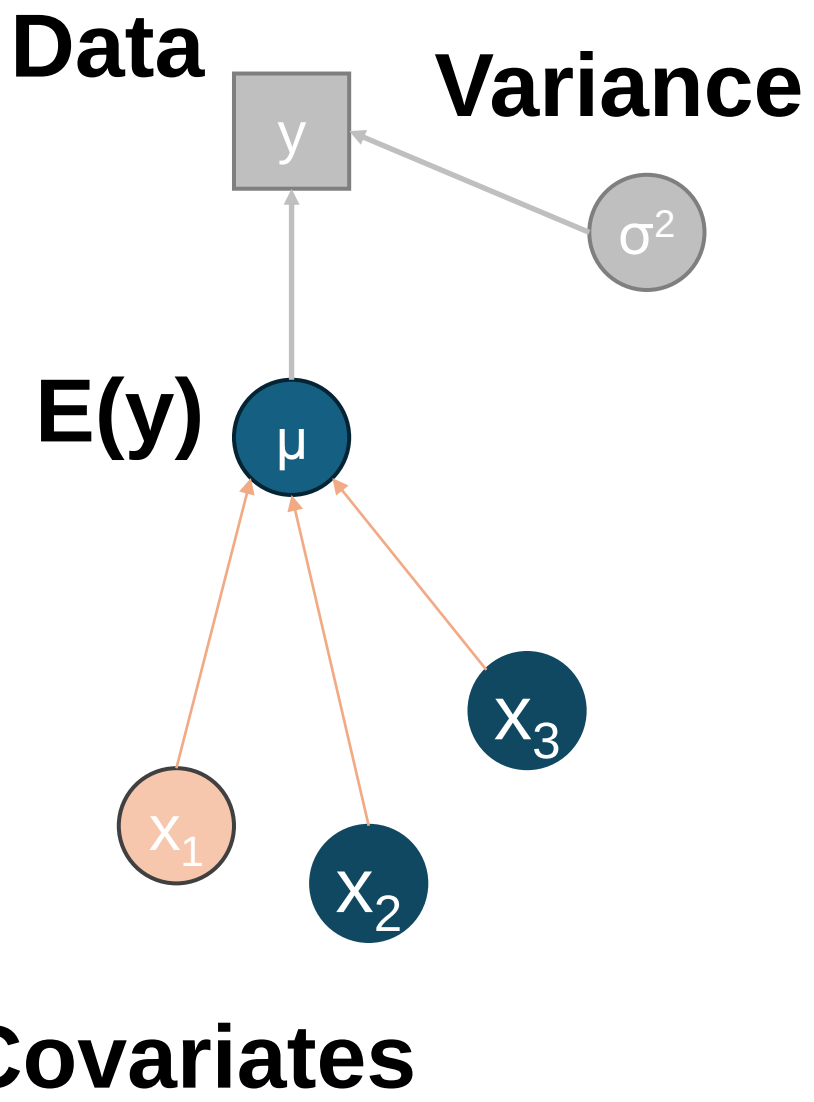
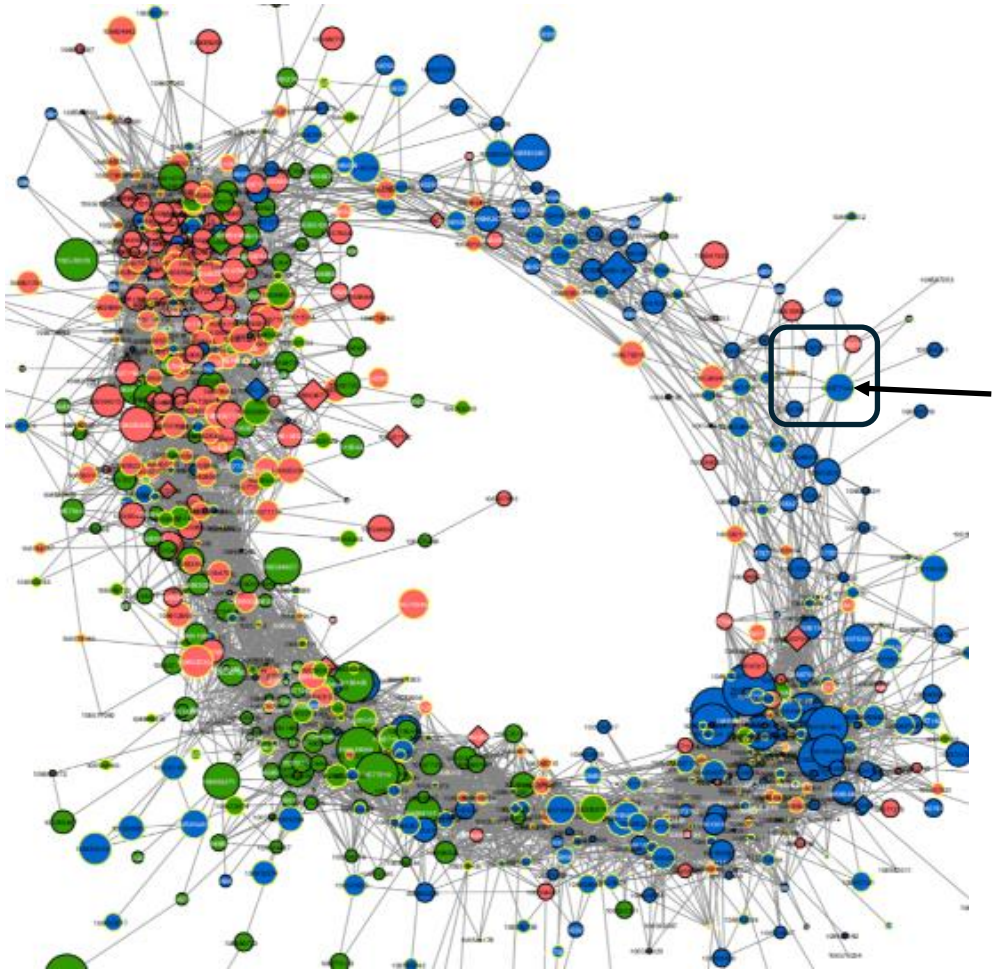


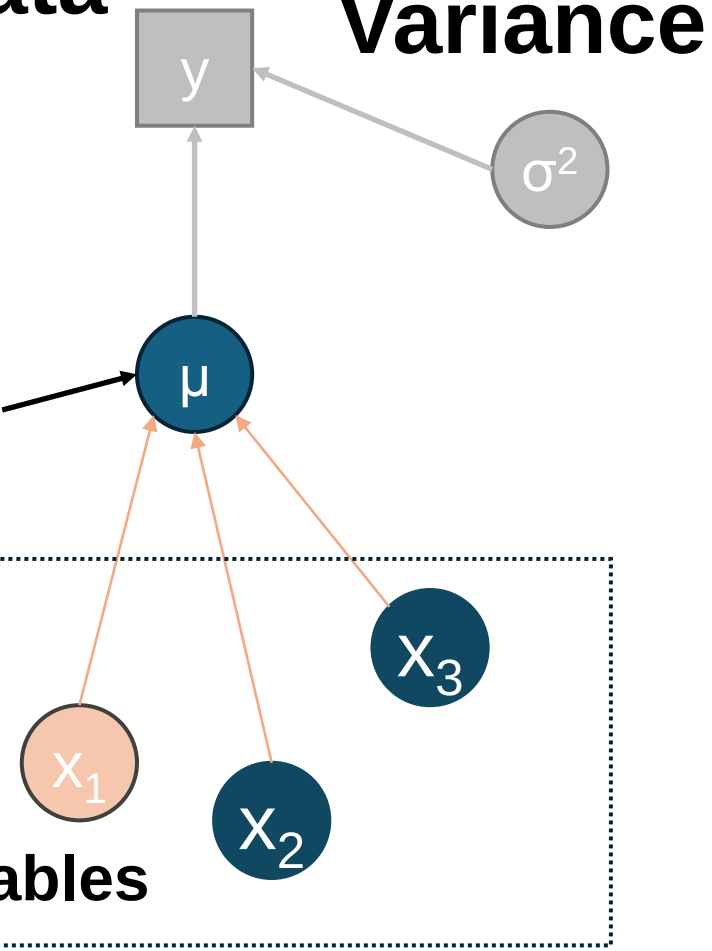
GLMs focus on a single response (i.e., dependent variable)…



Dependent variable

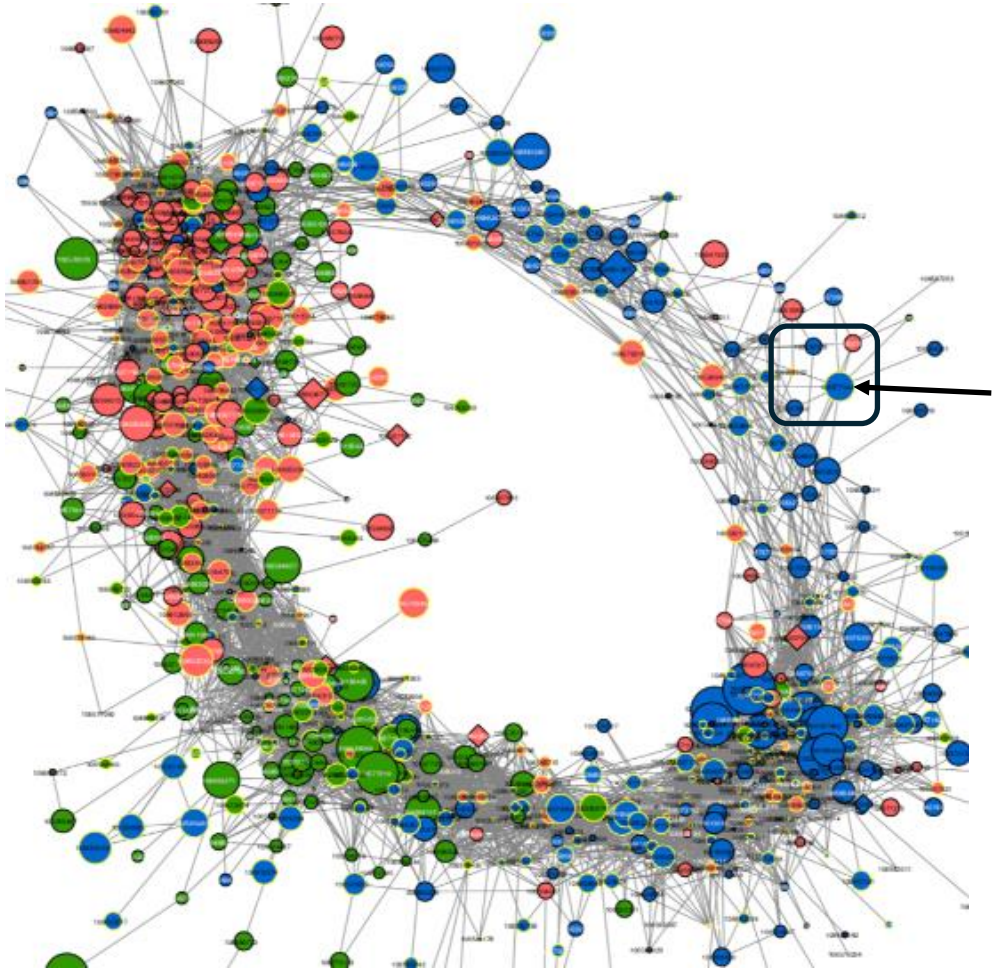
Data

Variance

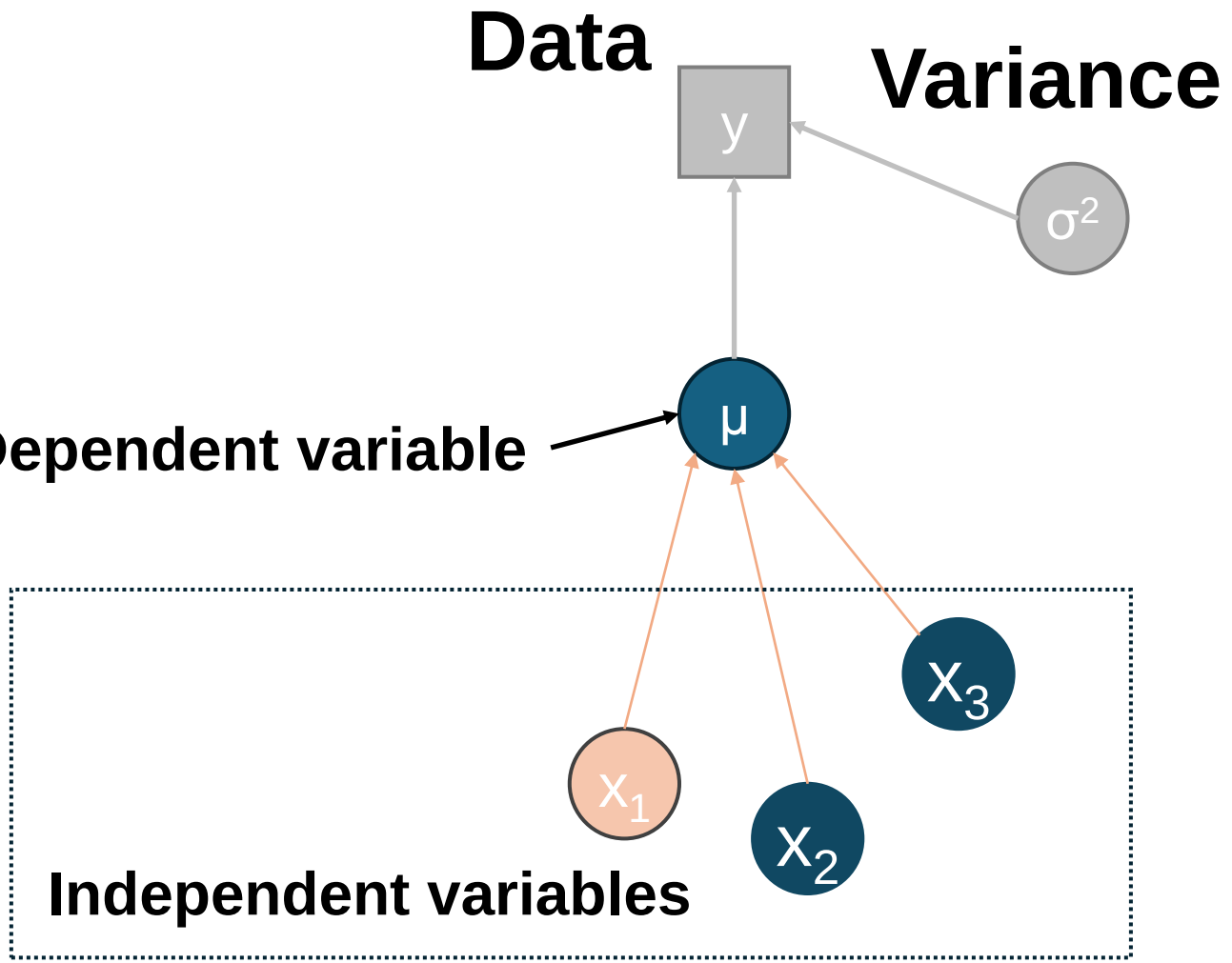


as a function of covariates (i.e., independent variables)

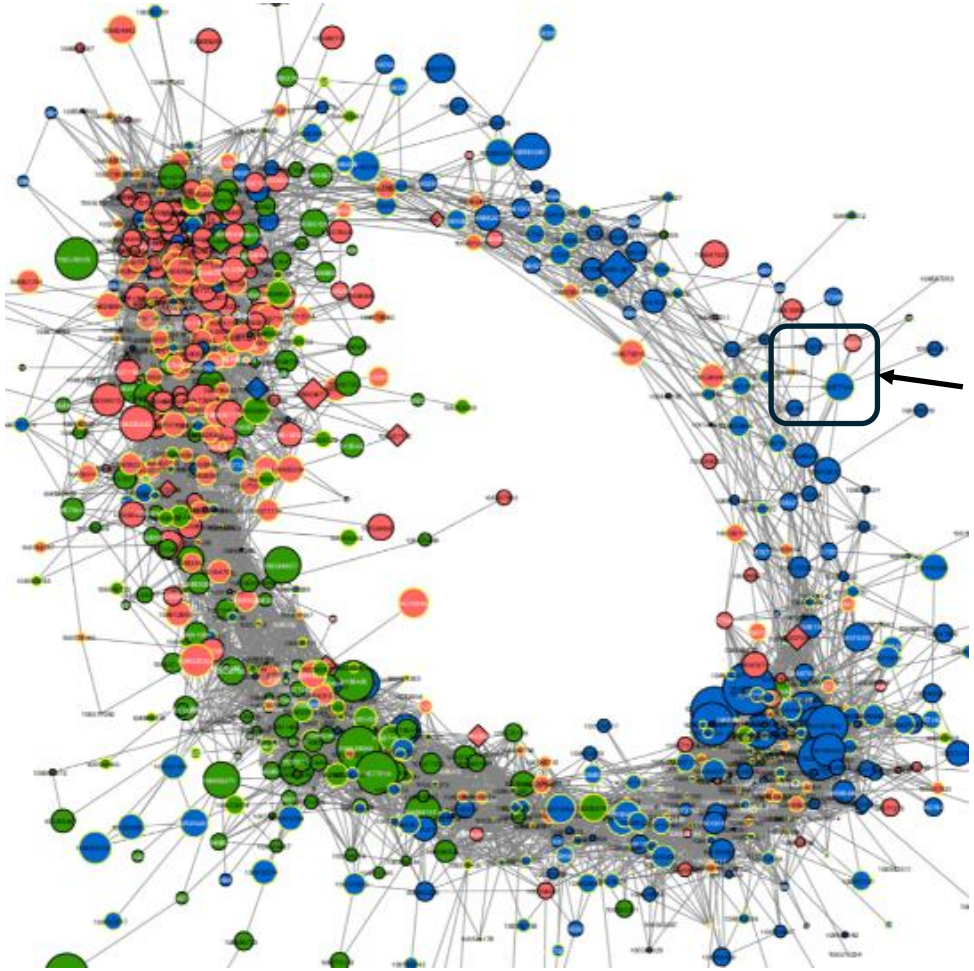
This is insufficient!

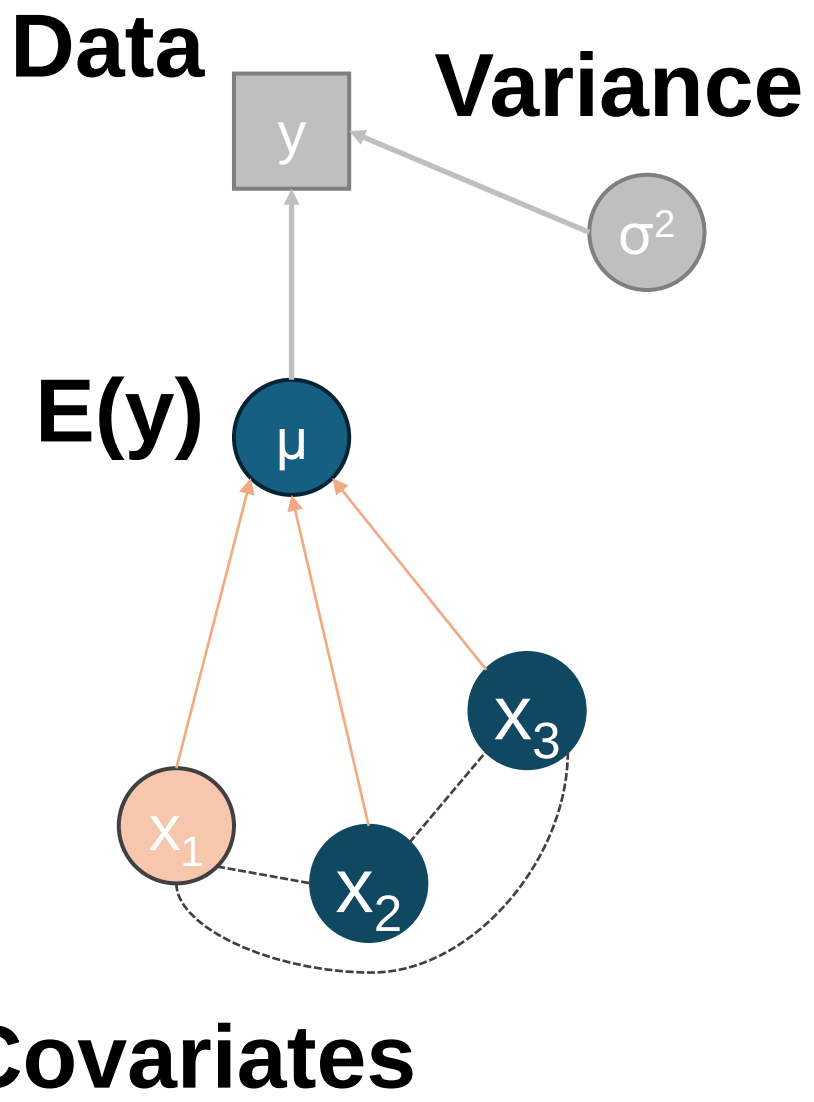


Dependent variable

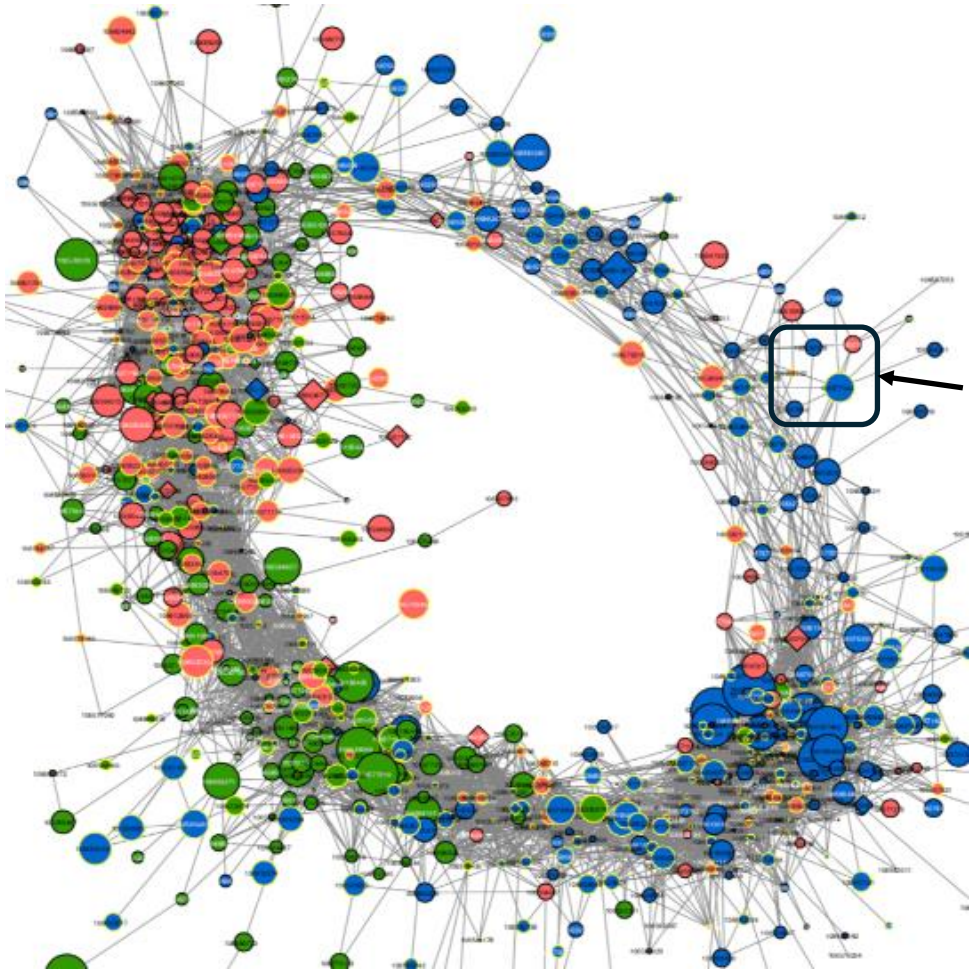


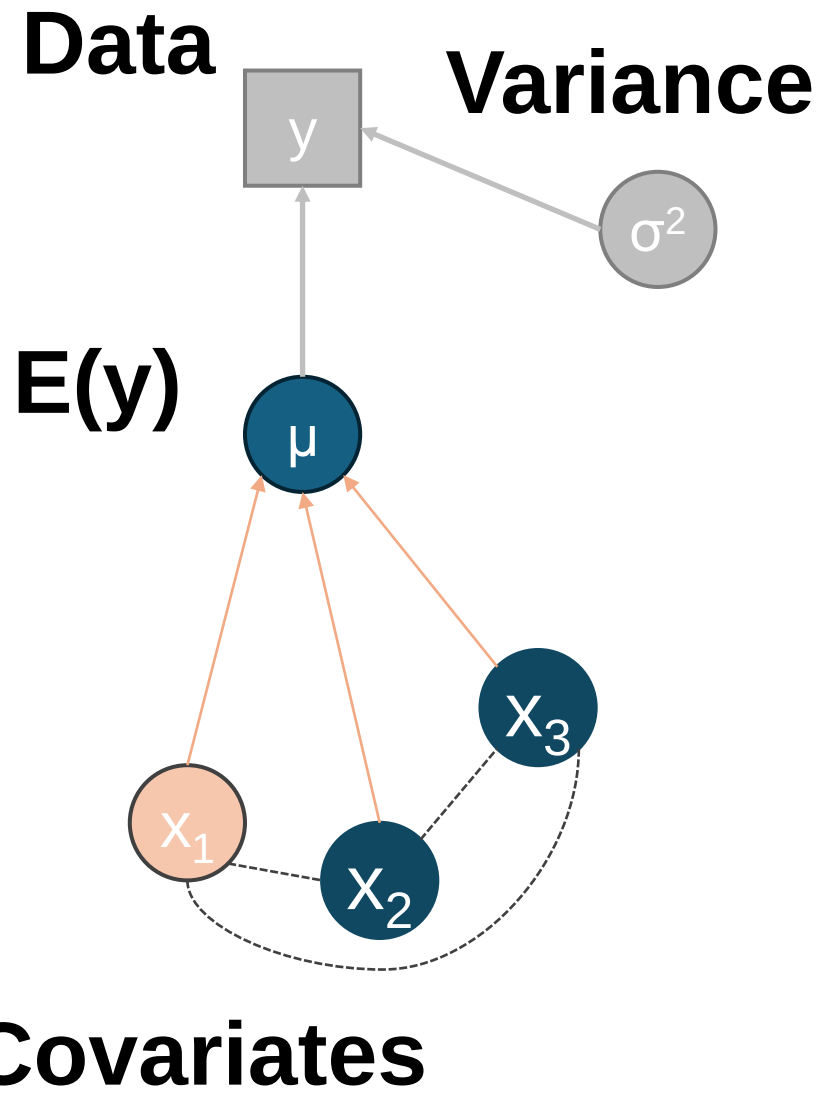
Covariates are often connected, or collinear (NOT ‘independent’)





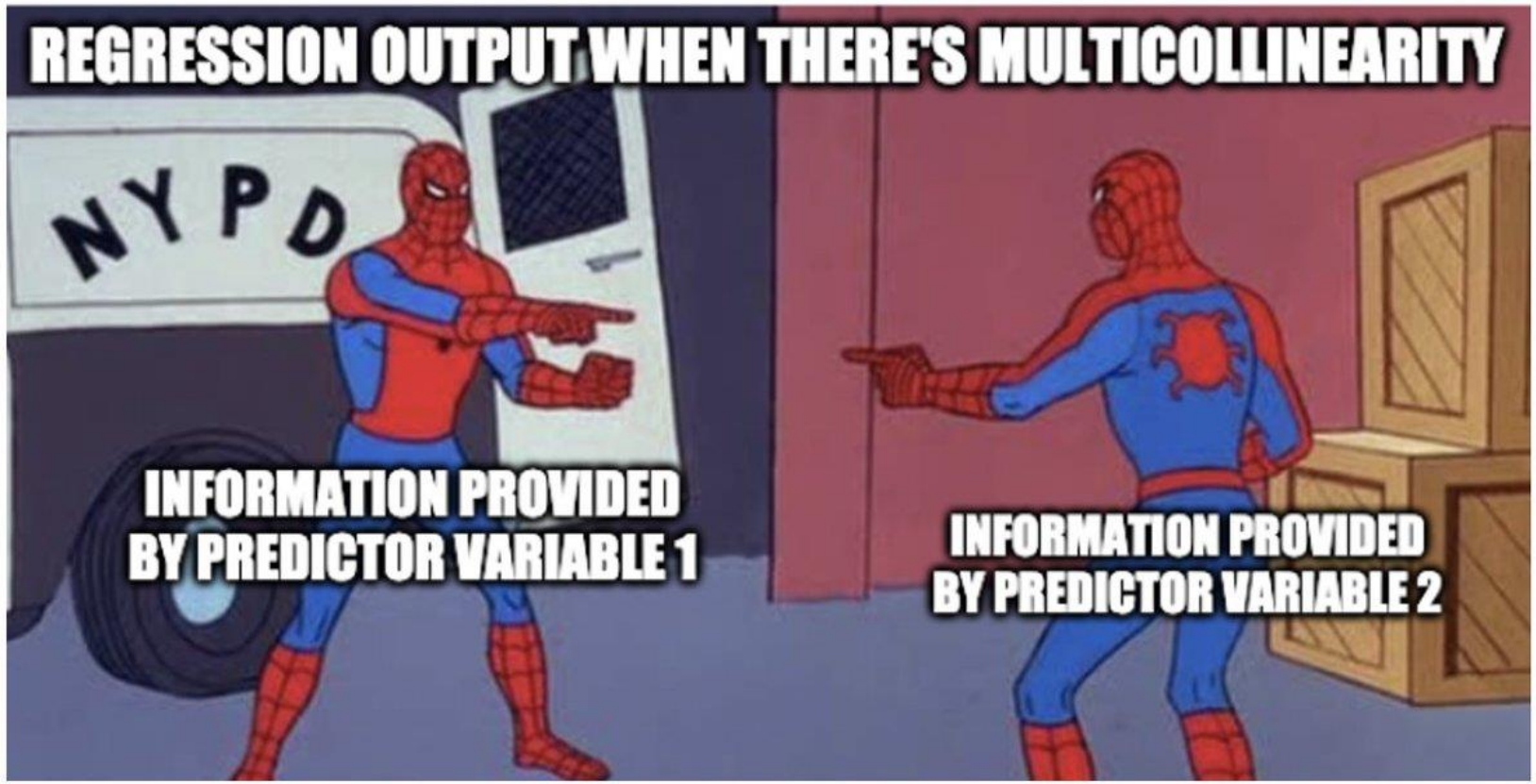
Multicollinearity is a major ‘problem’ in ecological analysis





How many of you have had to exclude collinear (r > 0.7) covariates?

Why did you do that?



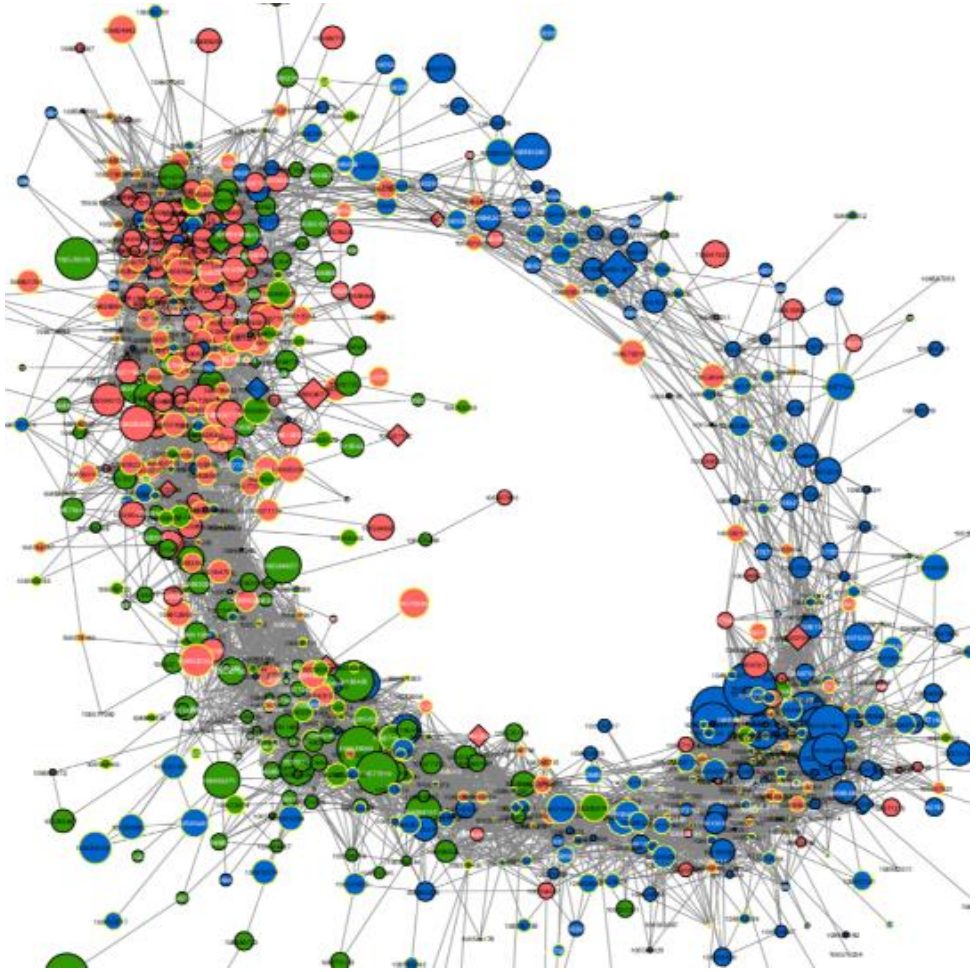
How did you exclude covariates?

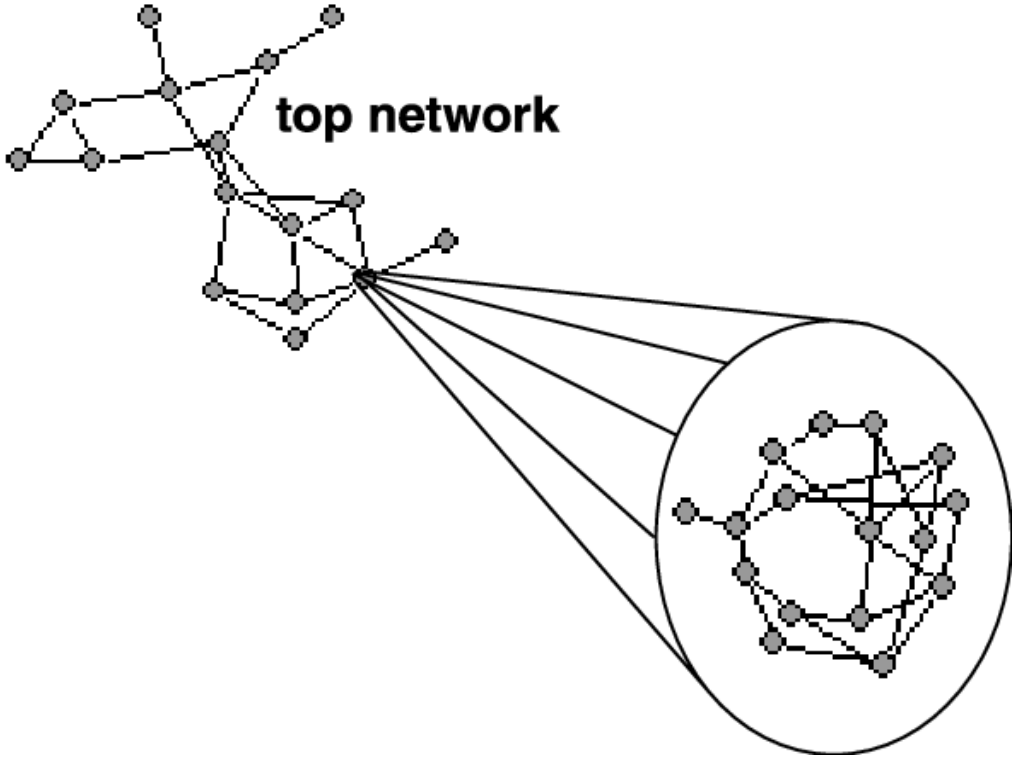
How did you exclude covariates?

- *a priori*
- test which fit ‘best’ (i.e., ‘iterative’ model selection?)
- haphazardly?
- r = 0.694... it’s fine!

How many of you felt ‘good’ about throwing away data?

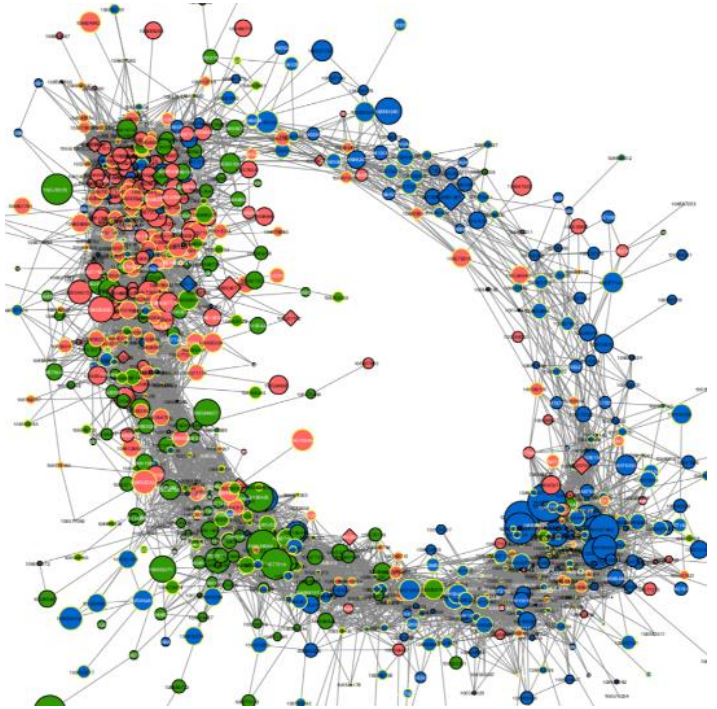
So… what do we do?





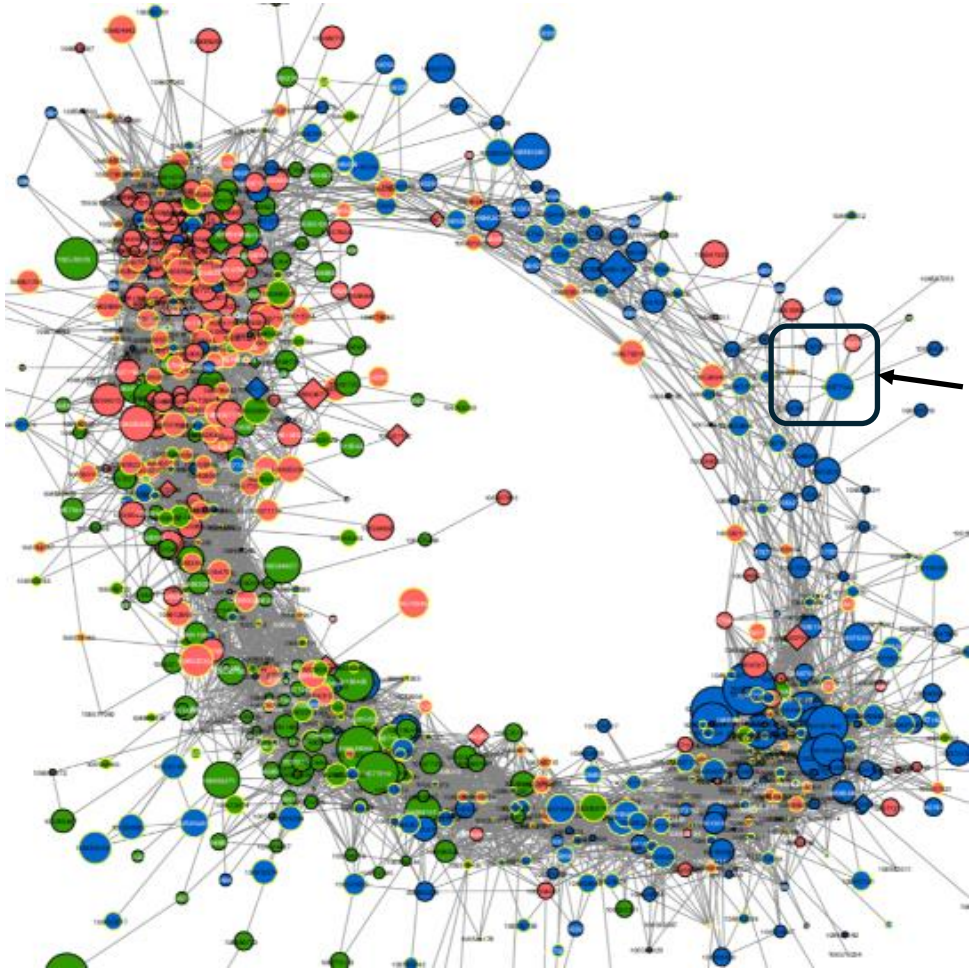
Instead of fighting or fearing multicollinearity…

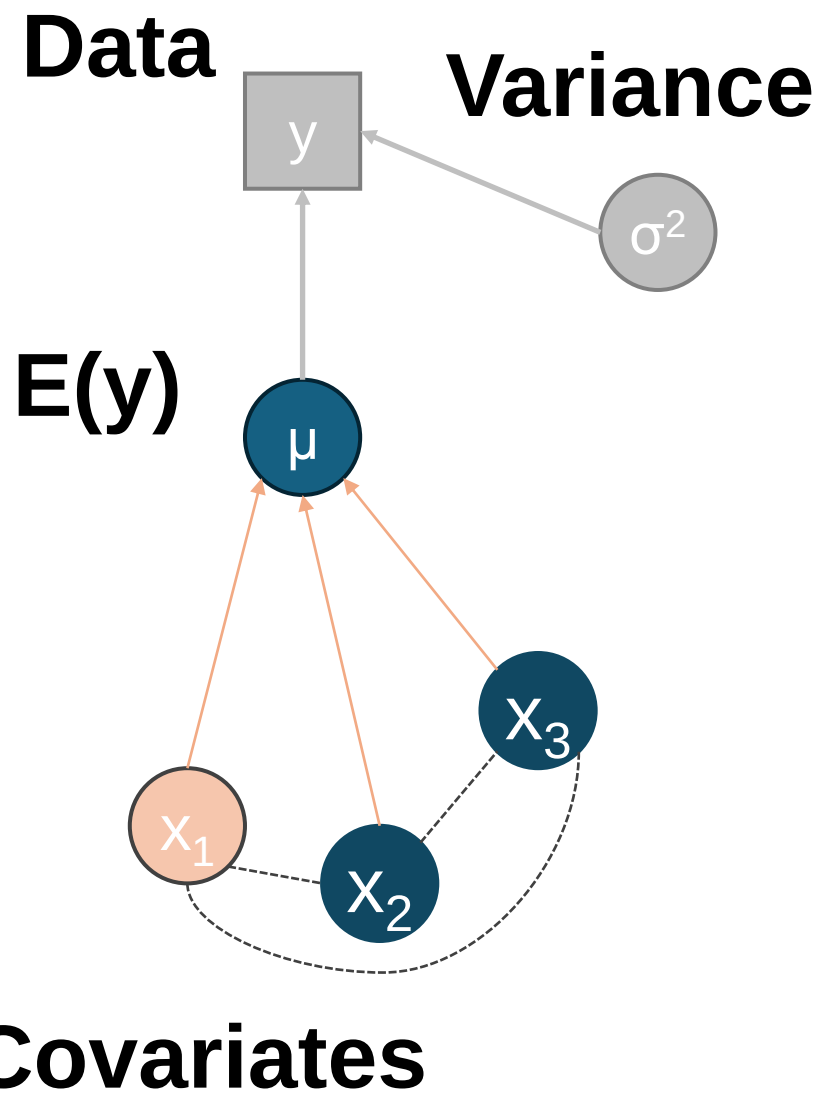
We should expect it, appreciate it, and seek to understand and use it.



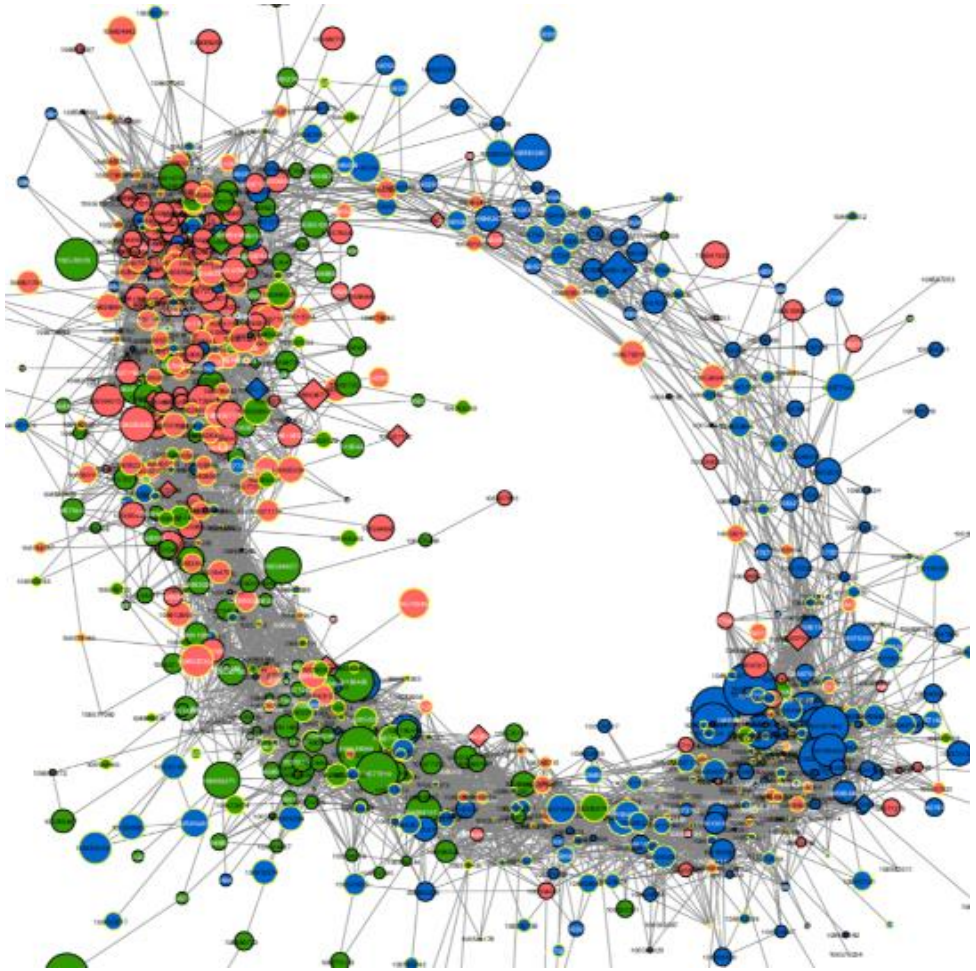
Why were they collinear?

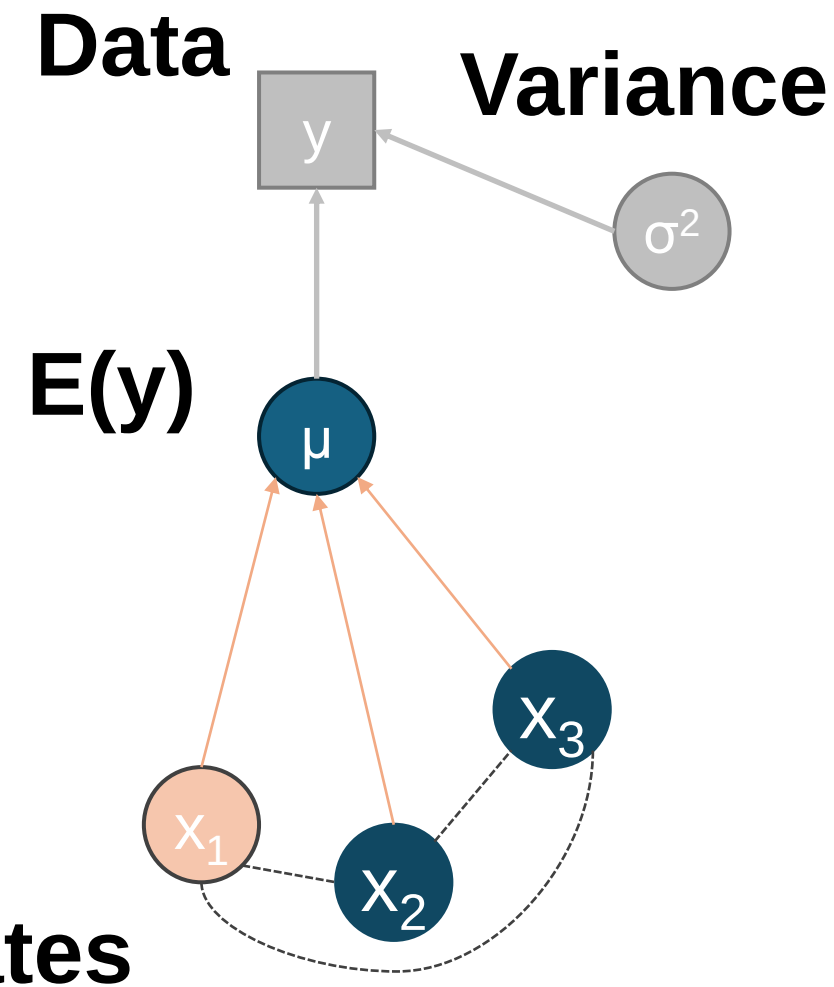
Why were they collinear? The motivating problem!





All models are wrong, but some are useful – GC Box





No models are right, and most are useless – TW Arnold

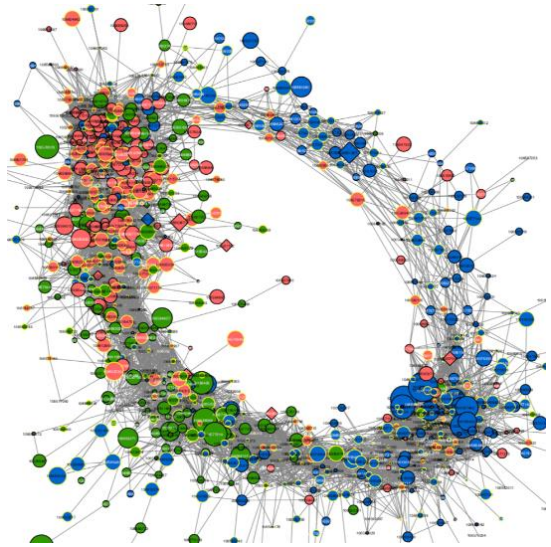
Why were they collinear?

1) ~~‘random’~~ or ~~‘spurious’?~~

2) **One covariate affects another**
   - e.g., elevation and snow or forest cover

3) **Both covariates are a result of an underlying latent process**
   - e.g., multiple morphometric measurements

The key idea for this workshop…



Can we model that* instead of pleading ‘multicollinearity’?

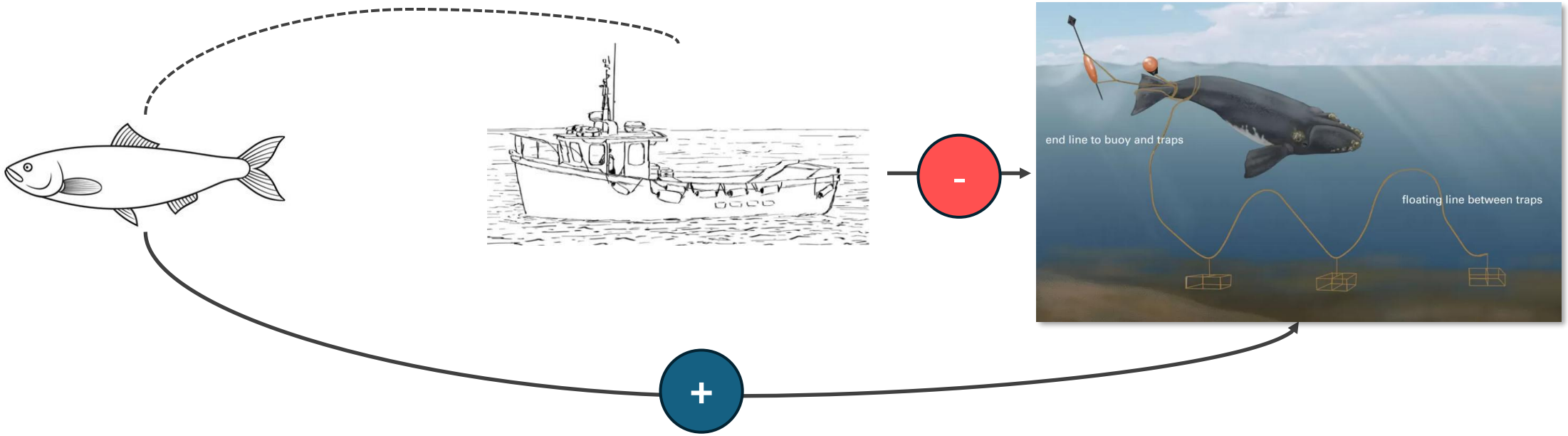
**No. Not in it’s entirety, reality is far too complicated for us to begin to comprehend*

We can do better...

The ‘intellectual leap’ is to be able to think about more than one response variable at a time

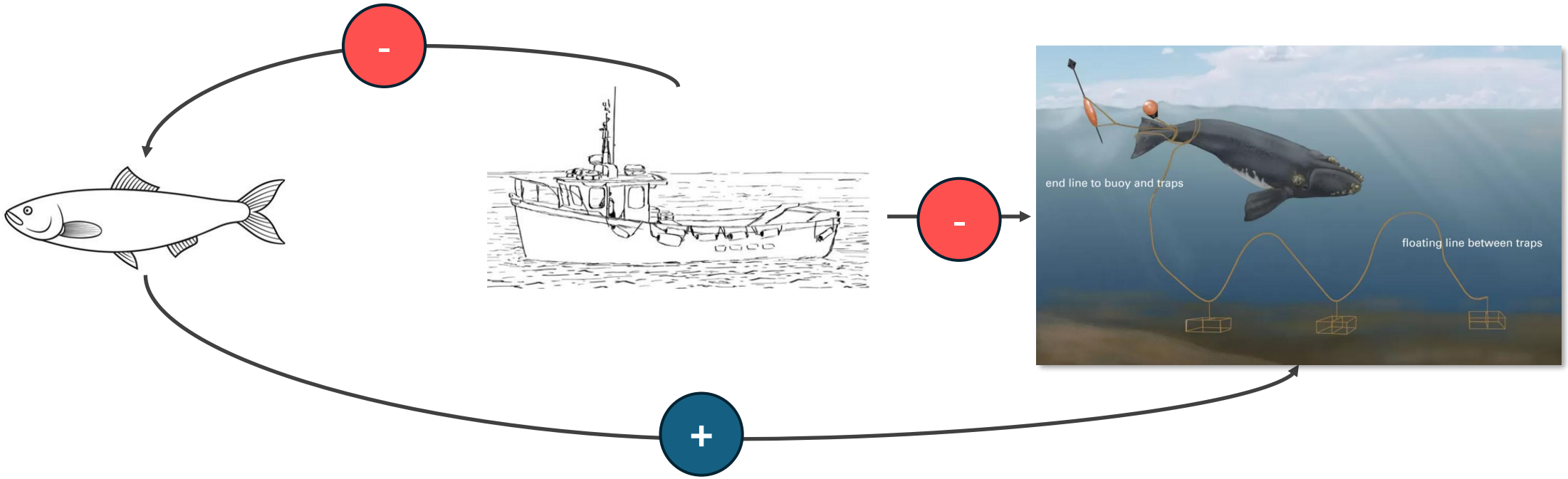
i.e., more than one variable will ‘depend’ on other variables...

GLM problem



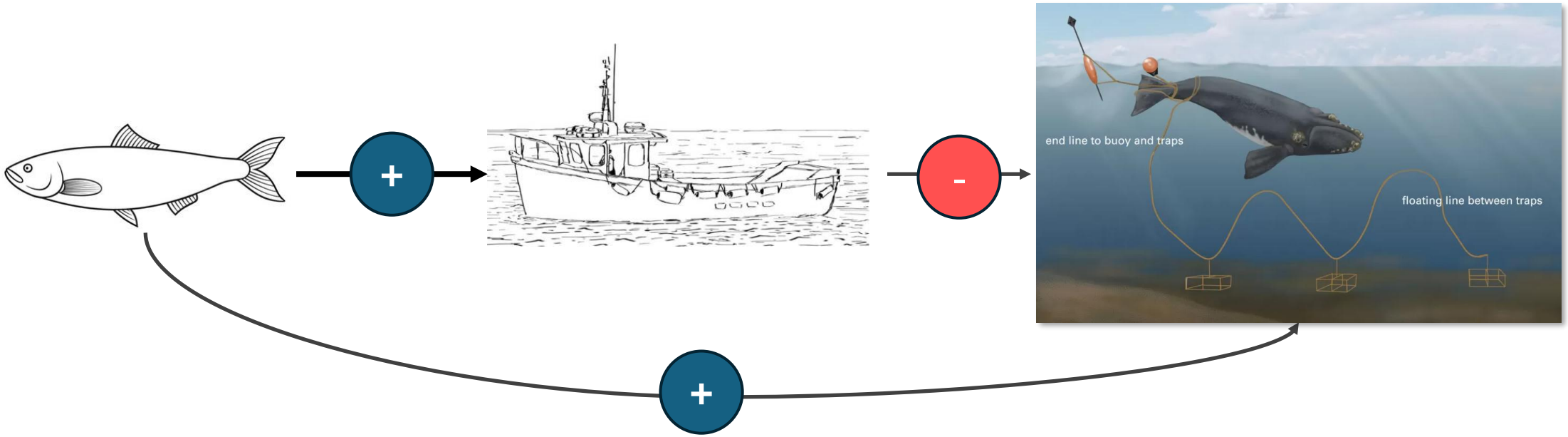
Fish and fishing are collinear because they affect each other

‘Path analysis’ solution



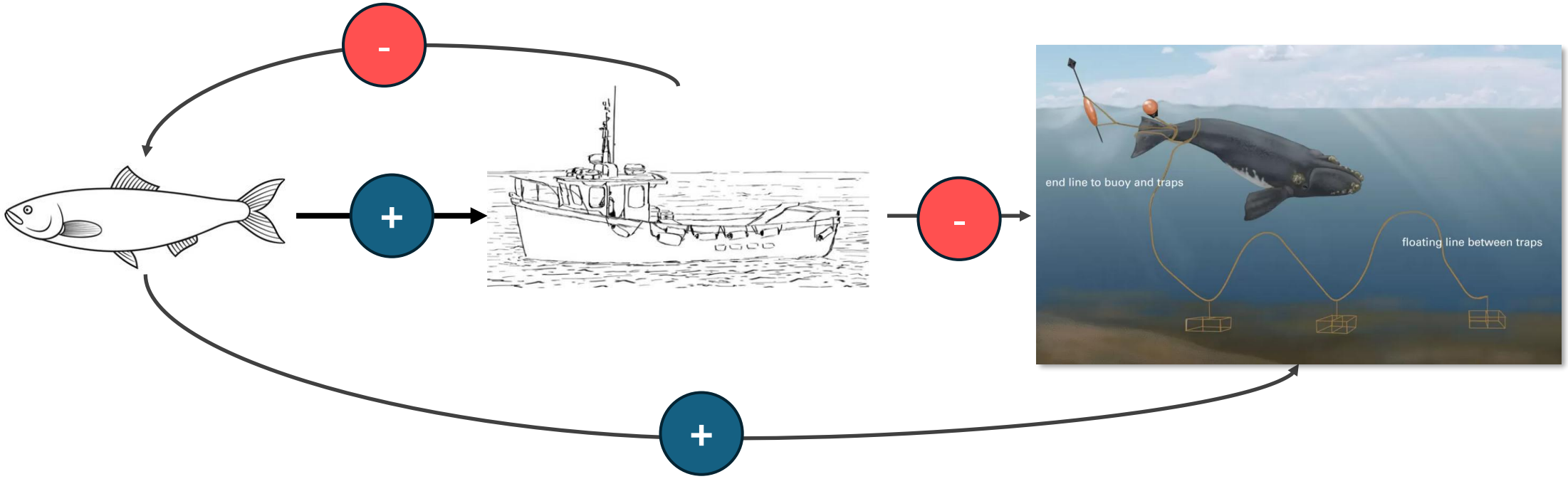
We can explicitly model those relationships

‘Path analysis’ solution



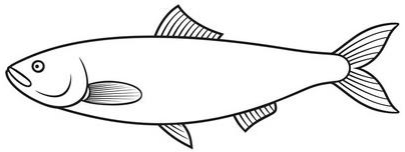
We can explicitly model those relationships

We can’t do this! Unless…



We can explicitly model those relationships

t = 1



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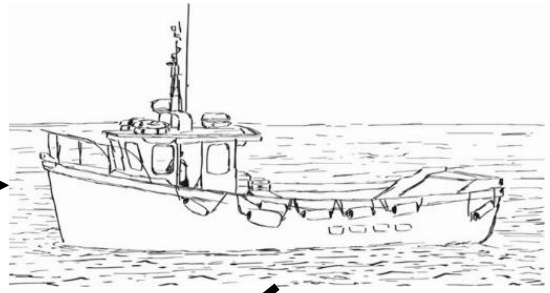

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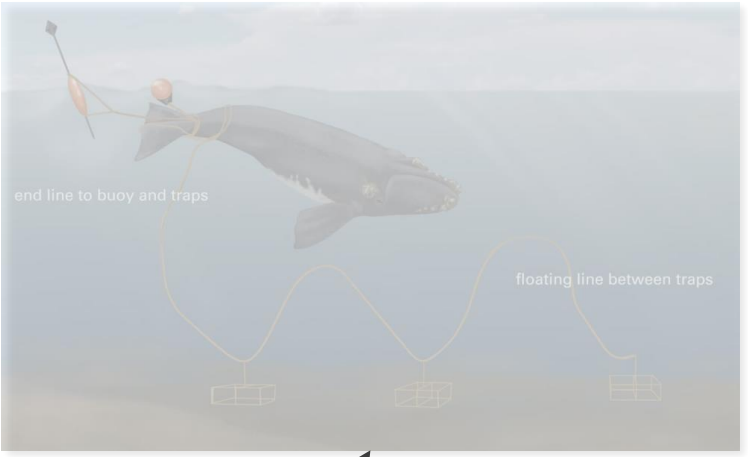
end line to buoy and traps
floating line between traps

+

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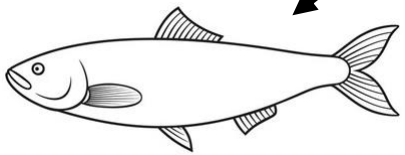

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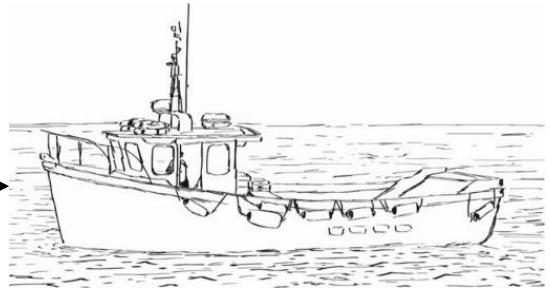

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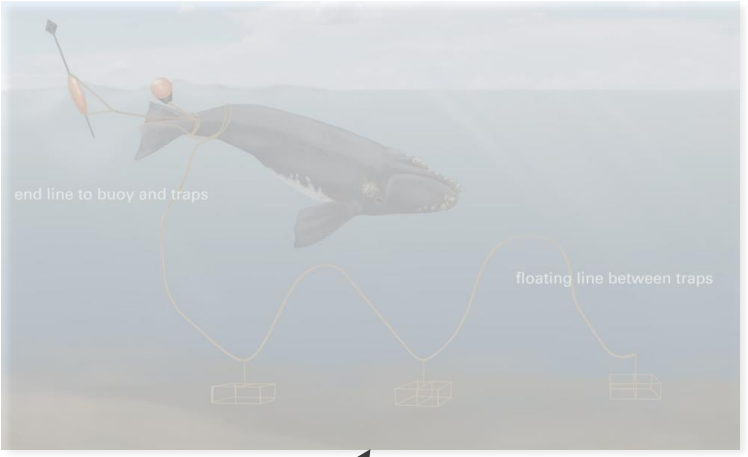
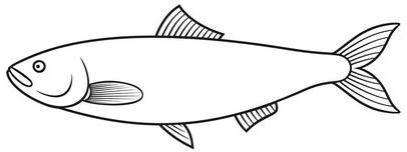

end line to buoy and traps
floating line between traps

+

t = 2

t = 1



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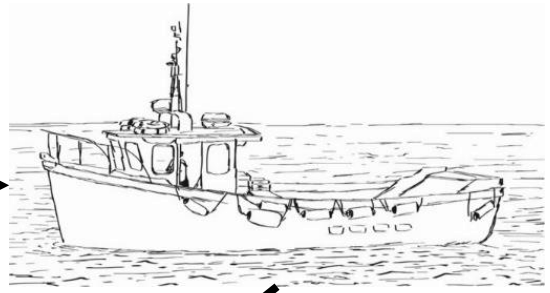

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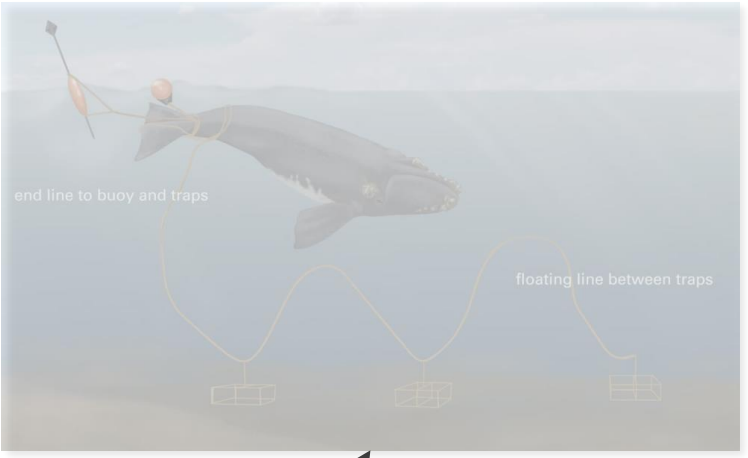

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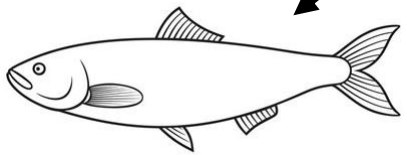
Dynamic SEMs

Cross-lags



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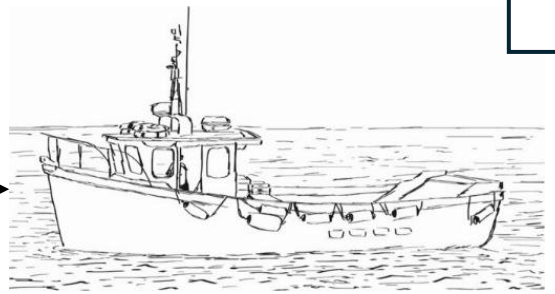

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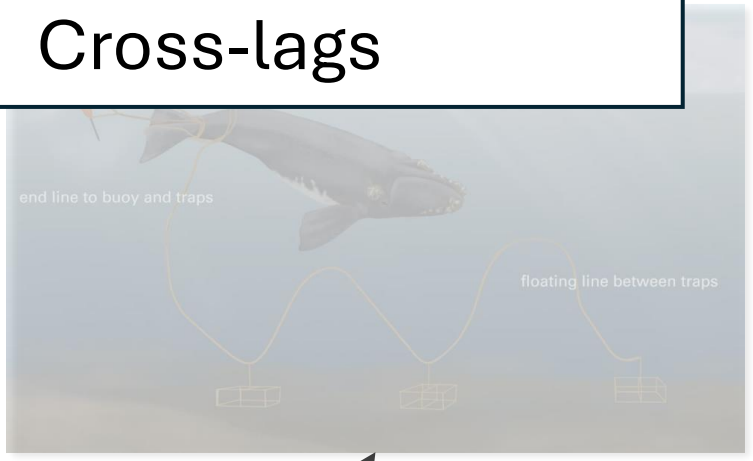

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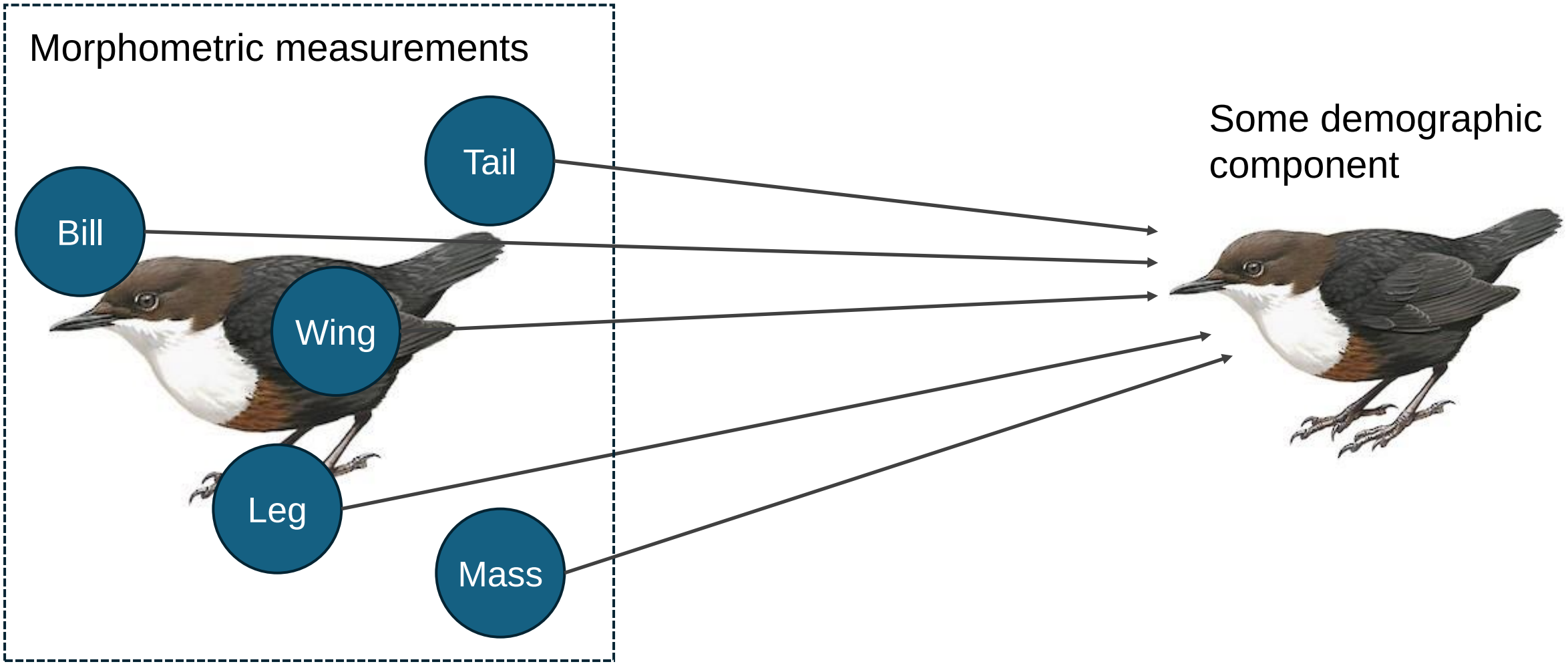
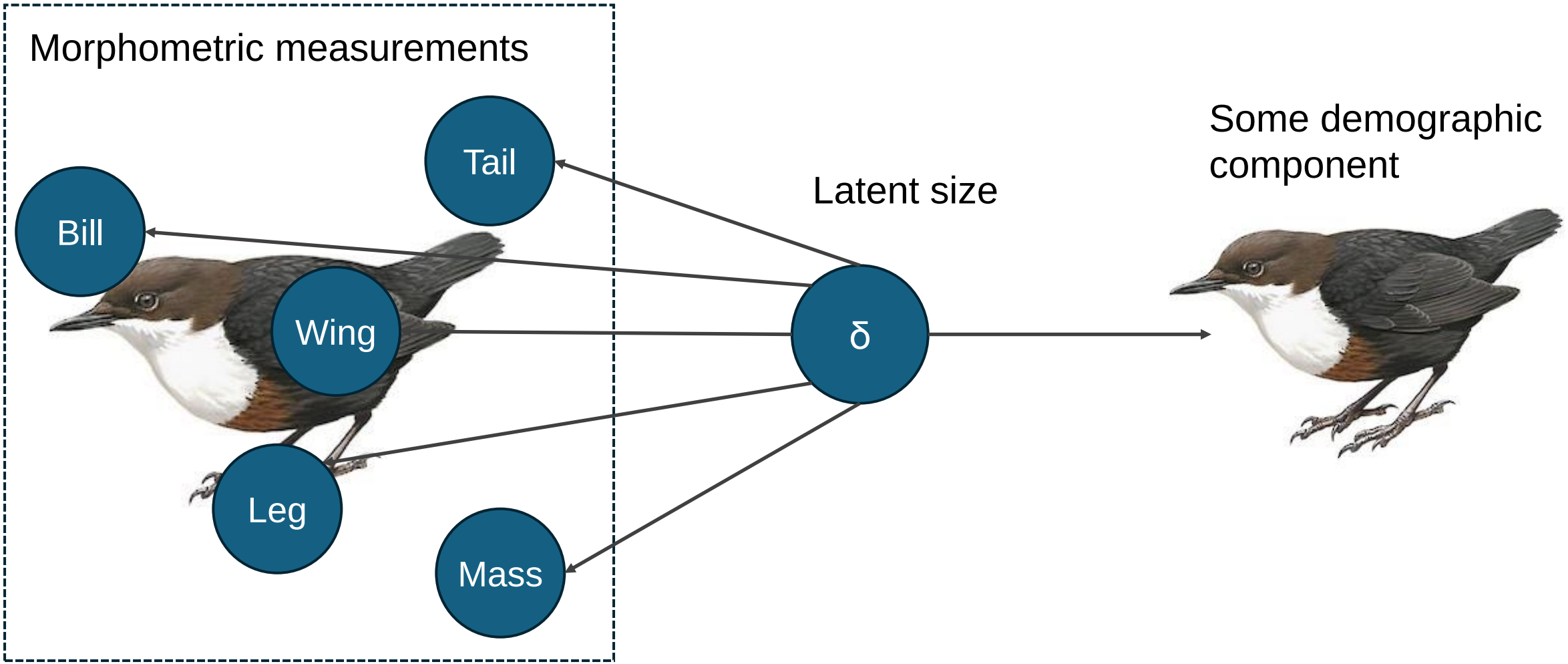
t = 2

GLM problem



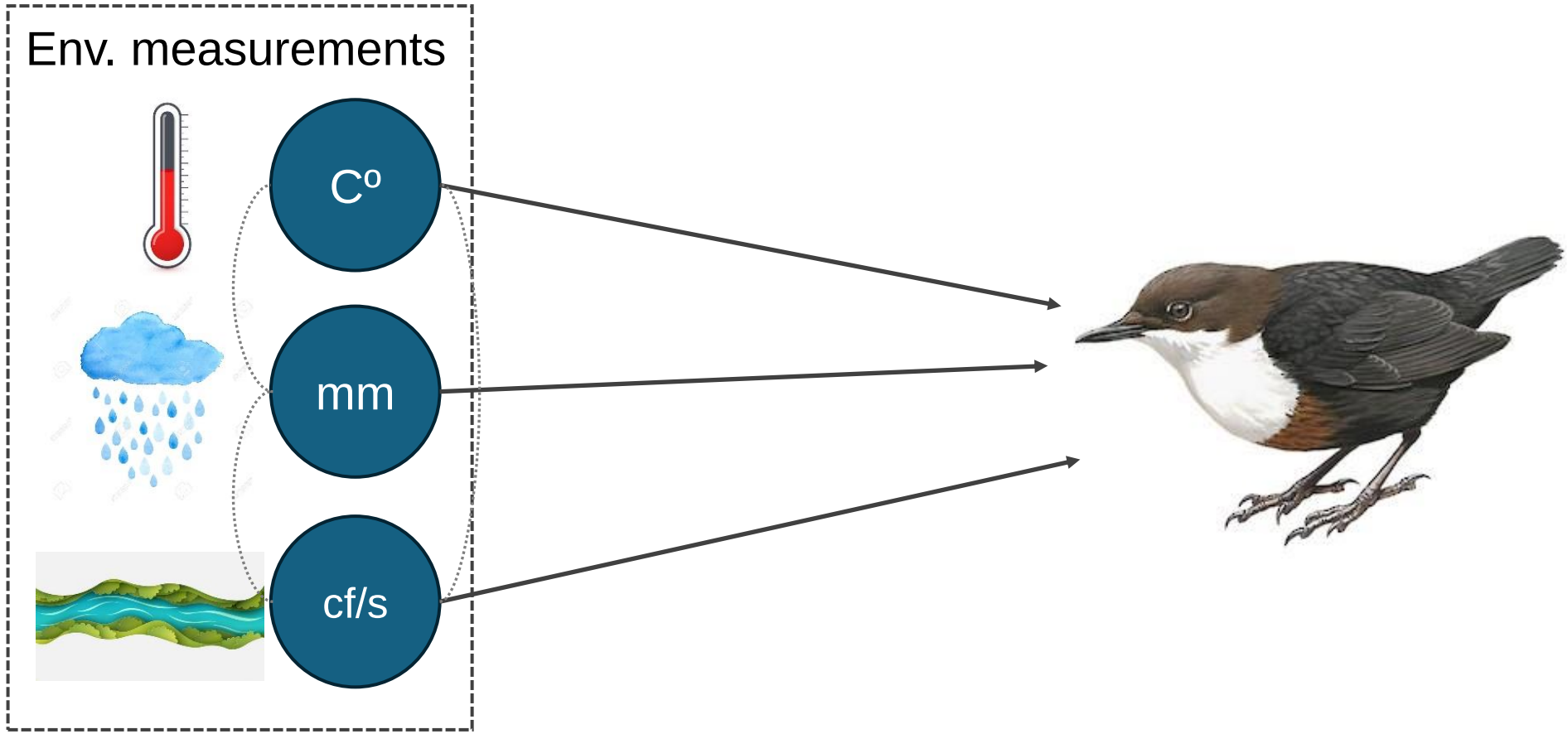
These are all measurement of different aspects of ‘size’

Latent variable solution



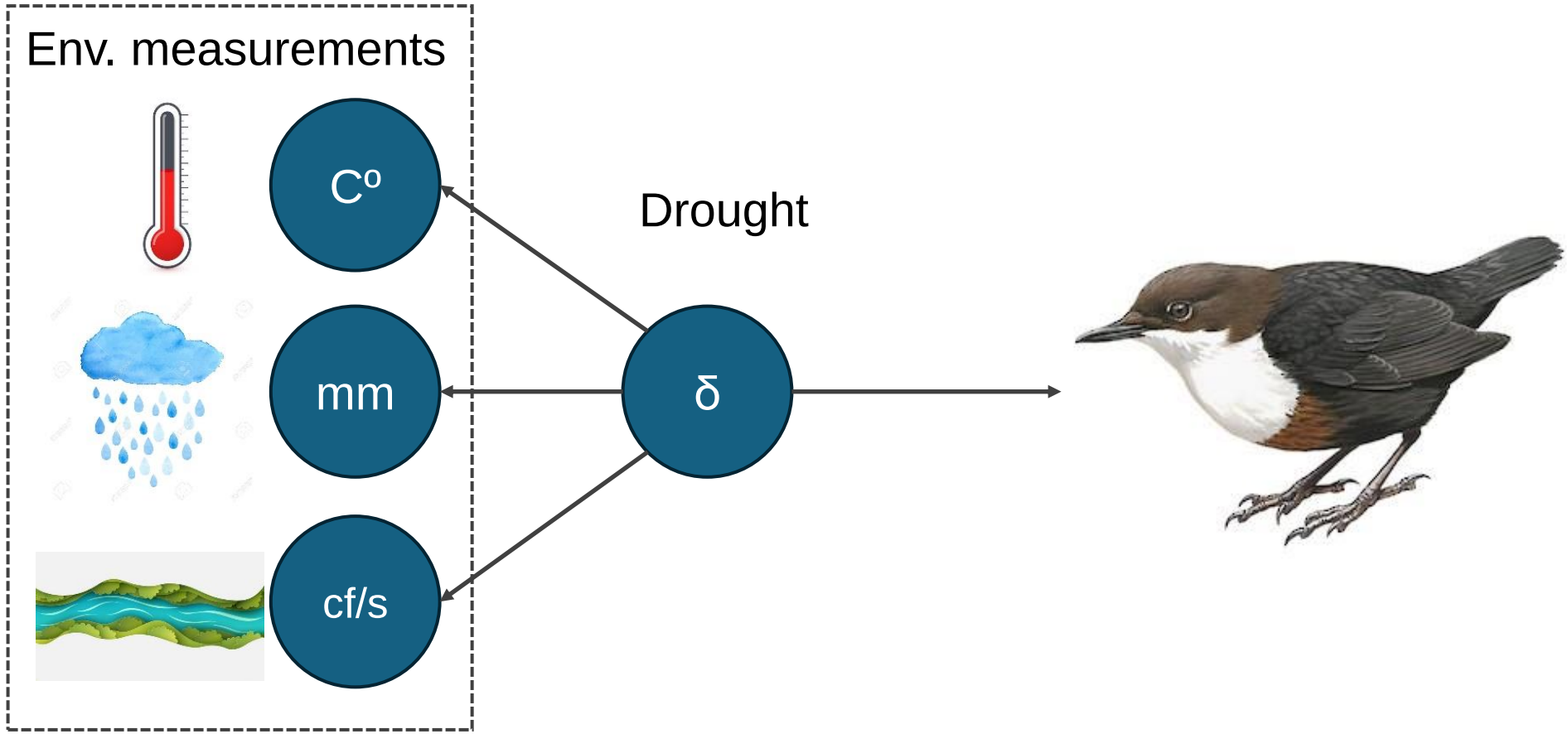
These are all measurement of different aspects of ‘size’

GLM problem



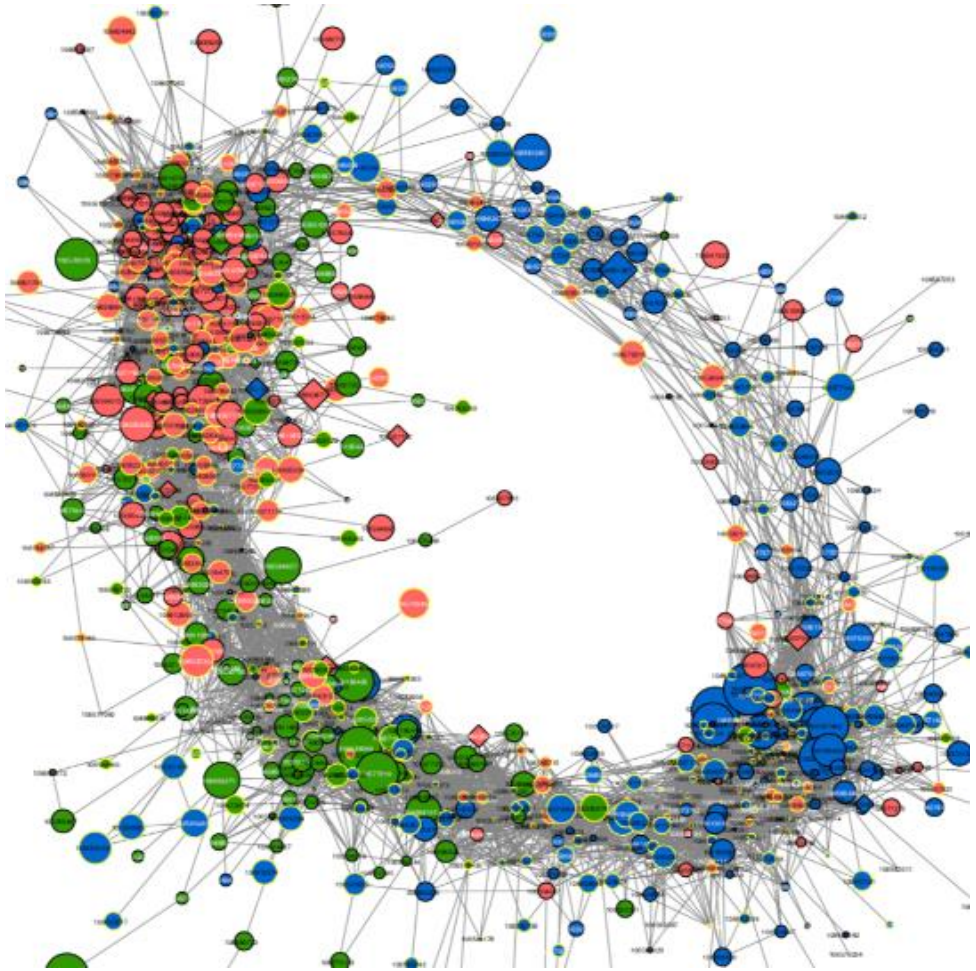
Flow rate, precipitation, and temperature as measurements of drought

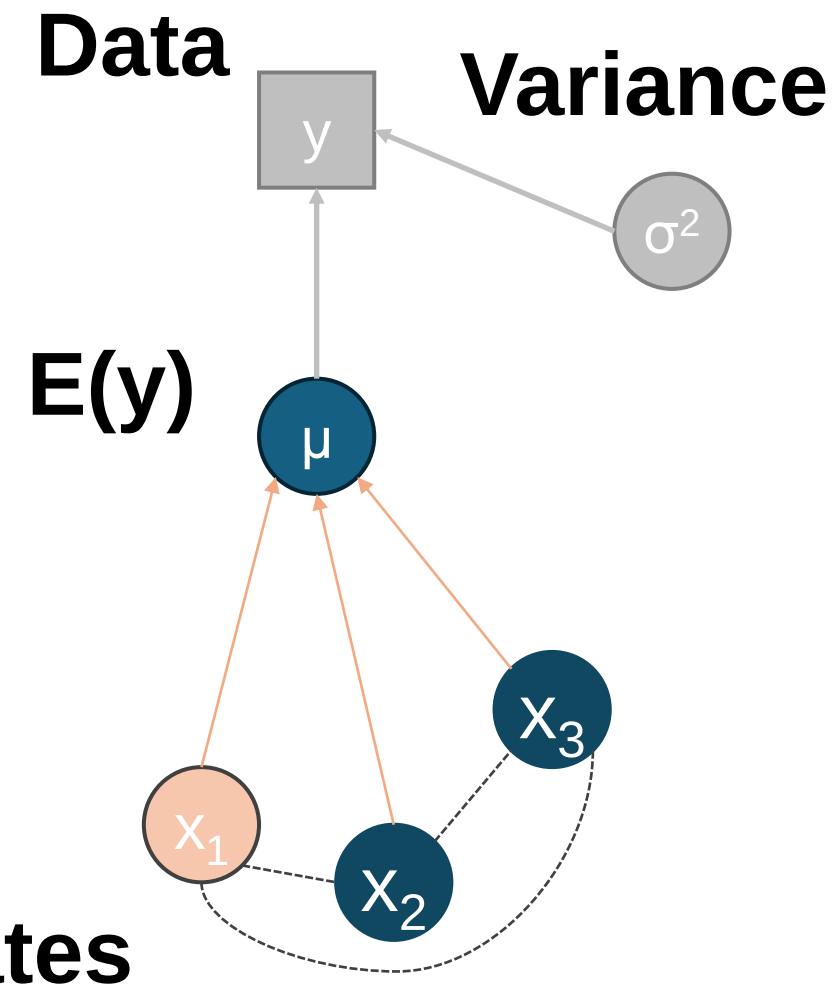
Latent variable solution



Flow rate, precipitation, and temperature as measurements of drought

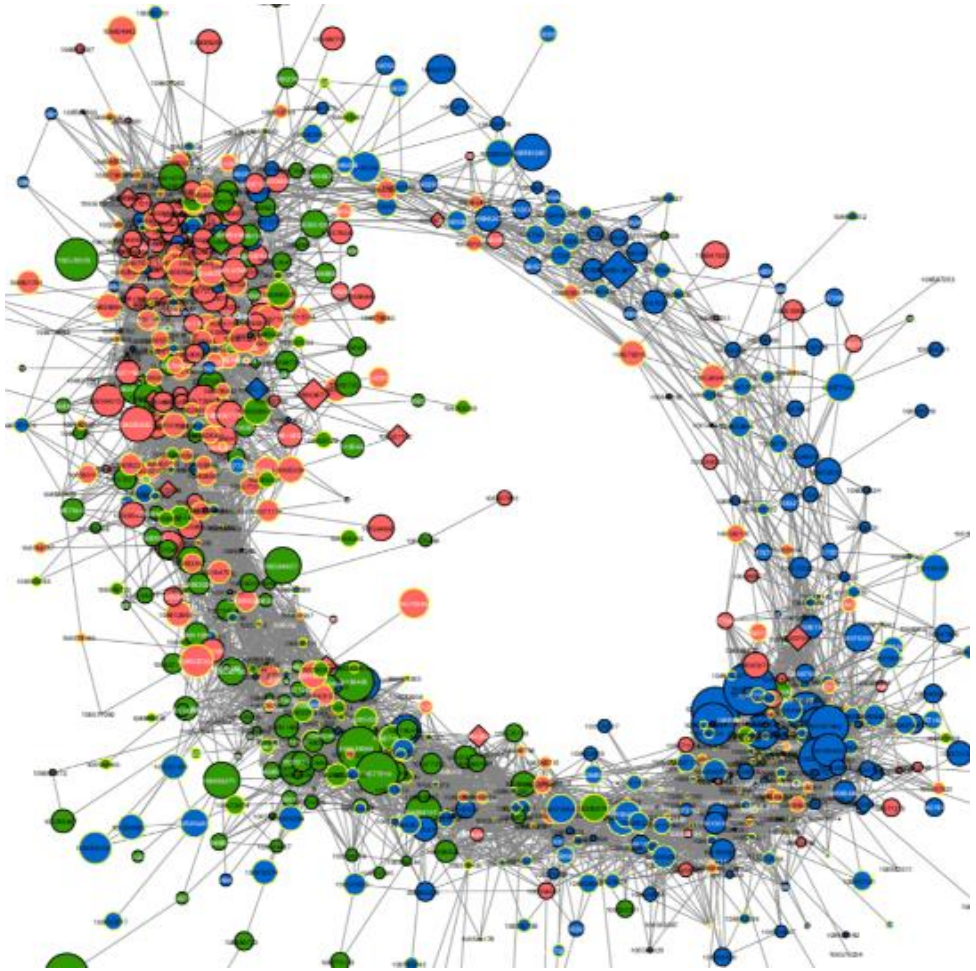
All models are wrong, but some are useful – GC Box

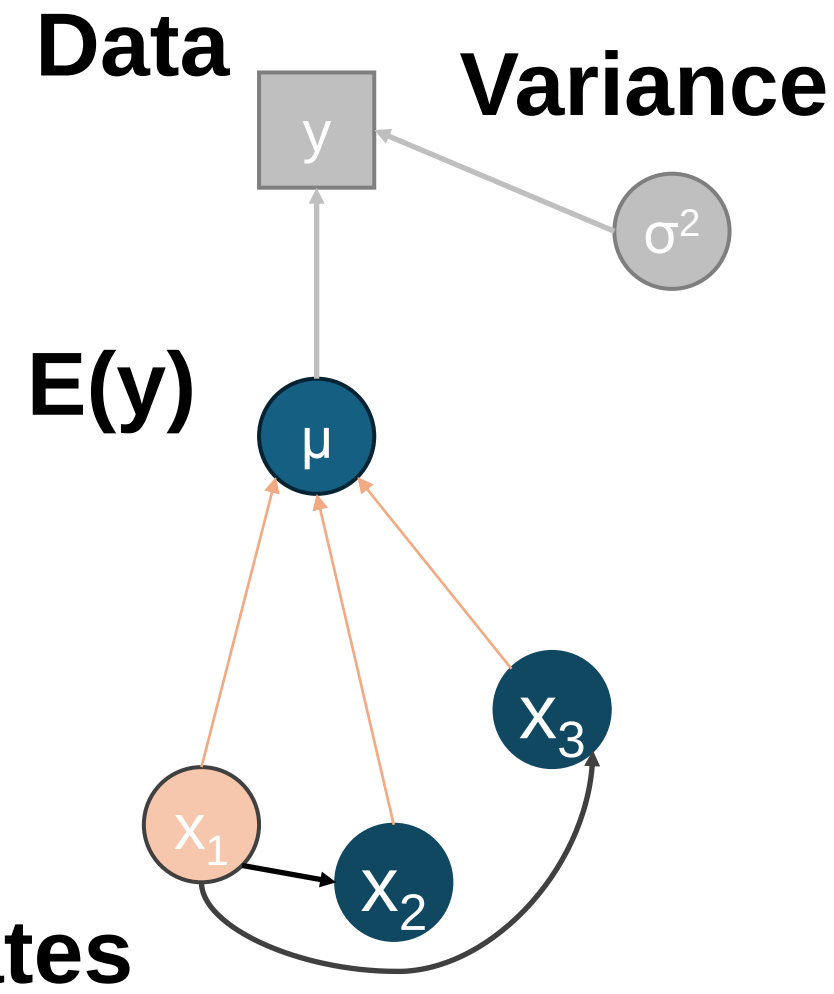




No models are right, and most are useless – TW Arnold

This model is a little less wrong, and potentially more useful?





***No models are right, and most are useless* – TW Arnold**

I’ve begun to use these approaches in my own research

Example(s): applied population dynamics (e.g., CMR, IPMs)

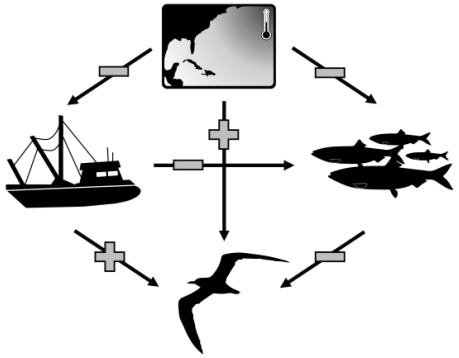


FIGURE 1 Simplified path diagram describing the hypothesized directionality (plus: Positive, bar: Negative association) regarding how environmental variables (i.e., sea-surface temperatures in the North Atlantic, fishery pressure, and fish production) influenced one another, as well as the indirect and direct pathways in which these sources of environmental variability influenced Royal tern mortality.

Received: 28 June 2022 | Revised: 26 September 2022 | Accepted: 5 October 2022

DOI: 10.1111/gcb.16482

Global Change Biology WILEY

RESEARCH ARTICLE

Climate change and commercial fishing practices codetermine survival of a long-lived seabird

Daniel Gibson[1,2] | Thomas V. Riecke[3] | Daniel H. Catlin[2] | Kelsi L. Hunt[2] | Chelsea E. Weithman[2] | David N. Koons[1] | Sarah M. Karpanty[2] | James D. Fraser[2]

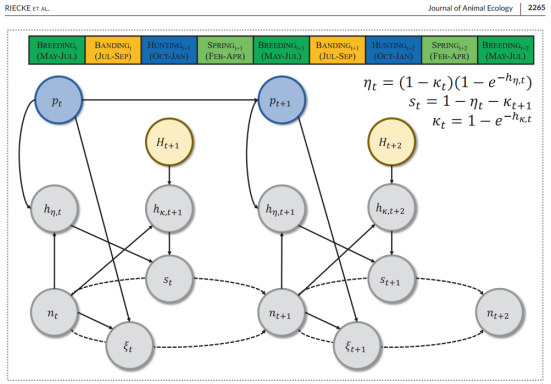


FIGURE 2 A directed acyclic graph demonstrating the relationships among abundance (n), ponds (p; blue), fecundity (ξ), hunting mortality hazard rate (h_κ), natural mortality hazard rate (h_η), survival (s) and the number of duck hunters (H; brown) for blue-winged teal breeding in the North American Prairie Pothole Region across the annual cycle (1973–3016). Solid arrows represent estimated directional relationships, and dashed arrows represent processes leading to changes in population abundance.

Received: 2 November 2021 | Accepted: 10 August 2022

DOI: 10.1111/1365-2656.13807

Journal of Animal Ecology BRITISH ECOLOGICAL SOCIETY

RESEARCH ARTICLE

Density-dependence produces spurious relationships among demographic parameters in a harvested species

Thomas V. Riecke[1,2,3] | Madeleine G. Lohman[1,2] | Benjamin S. Sedinger[1,2,4] | Todd W. Arnold[5] | Cliff L. Feldheim[6] | David N. Koons[7] | Frank C. Rohwer[8] | Michael Schaub[3] | Perry J. Williams[2] | James S. Sedinger[2]

[1]Graduate Program in Ecology, Evolution, and Conservation Biology, University of Nevada, Reno, Nevada, USA; [2]Department of Natural Resources and Environmental Science, University of Nevada, Reno, Nevada, USA; [3]Swiss Ornithological Institute, Sempach, Switzerland; [4]University of Wisconsin–Stevens Point, Stevens Point, Stevens Point, Wisconsin, USA; [5]Department of Fisheries, Wildlife, and Conservation Biology, University of Minnesota, St. Paul, Minnesota, USA; [6]California Trout, San Francisco, California, USA; [7]Fish, Wildlife, and Conservation Biology & Graduate Degree Program in Ecology, Colorado State University, Ft. Collins, Colorado, USA and [8]Delta Waterfowl Foundation, Bismarck, North Dakota, USA

Gibson, Riecke, et al. **(2023)** *Global Change Biology*

Riecke et al. **(2022b)** *Journal of Animal Ecology*

Example: basic evolutionary demography (e.g., LRS, senescence)

Estimating latent heterogeneity in individual fitness using structural equation models

Thomas V. Riecke[1,2,3], Rémi Fay[4], Johann Hegelbach[5], Pierre-Alain Ravussin[6], Daniel Arrigo[7] and Michael Schaub[1]

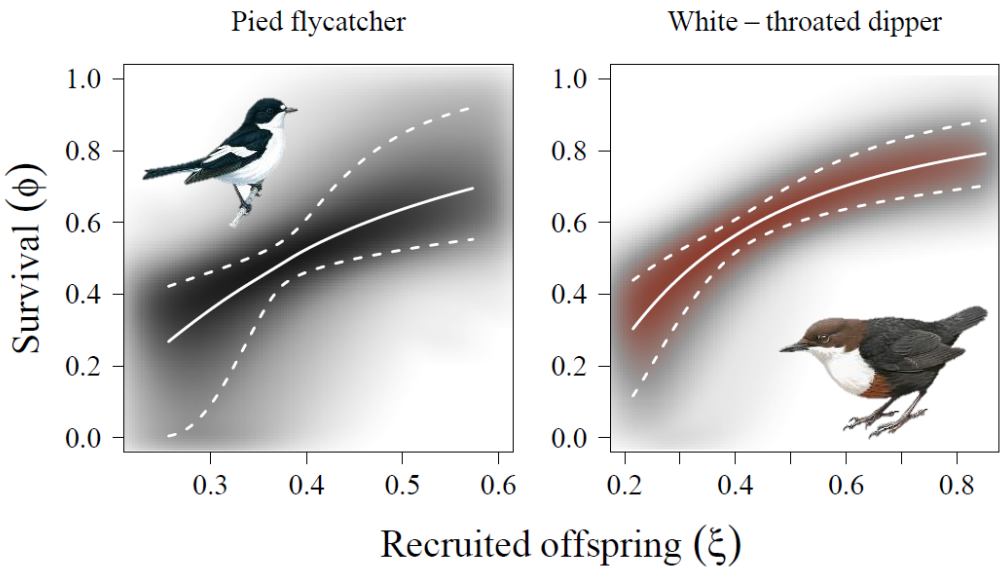


Figure 1. Medians (solid lines) and 95% confidence intervals (dashed lines) for joint estimates of survival (ϕ) and mean recruits per breeding season (ξ) of one-year-old European pied flycatcher (left; *Ficedula hypoleuca*) and white-throated dipper (right; *Cinclus cinclus*) females breeding in Switzerland. The density of the shading corresponds to the density of the posterior distribution.

Riecke et al. **(in rejection)** *Ecology*

Received: 22 April 2022 | Accepted: 10 January 2023
DOI: 10.1111/1365-2656.13893
Journal of Animal Ecology
RESEARCH ARTICLE

Reproductive senescence and mating tactic interact and conflict to drive reproductive success in a passerine

Thomas V. Riecke[1] | Johann Hegelbach[2] | Michael Schaub[1]

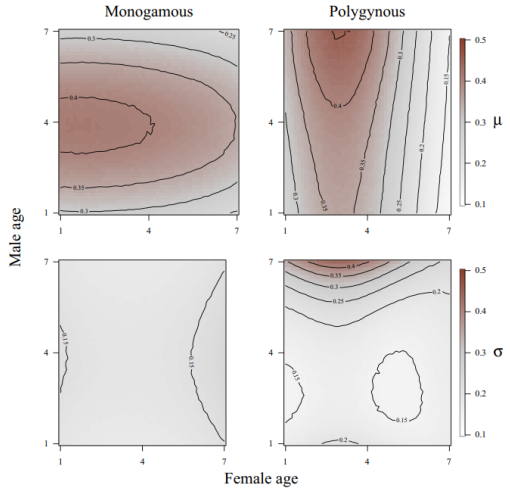


FIGURE 5 Image and contour plots of the means (μ; top) and standard deviations (σ; bottom) of the predicted number of locally recruited offspring from monogamous (left) and polygynous (right) breeding attempts by known-age dipper pairs breeding along the River Sihl near Zurich, Switzerland (1989–2018).

Riecke et al. **(2023)** *Journal of Animal Ecology*

These tools have transformed how I do research.

I still have a tremendous amount to learn* (it's been three years)!

*I also use them almost exclusively in JAGS and Stan, so we're on thin ice today!

Ok

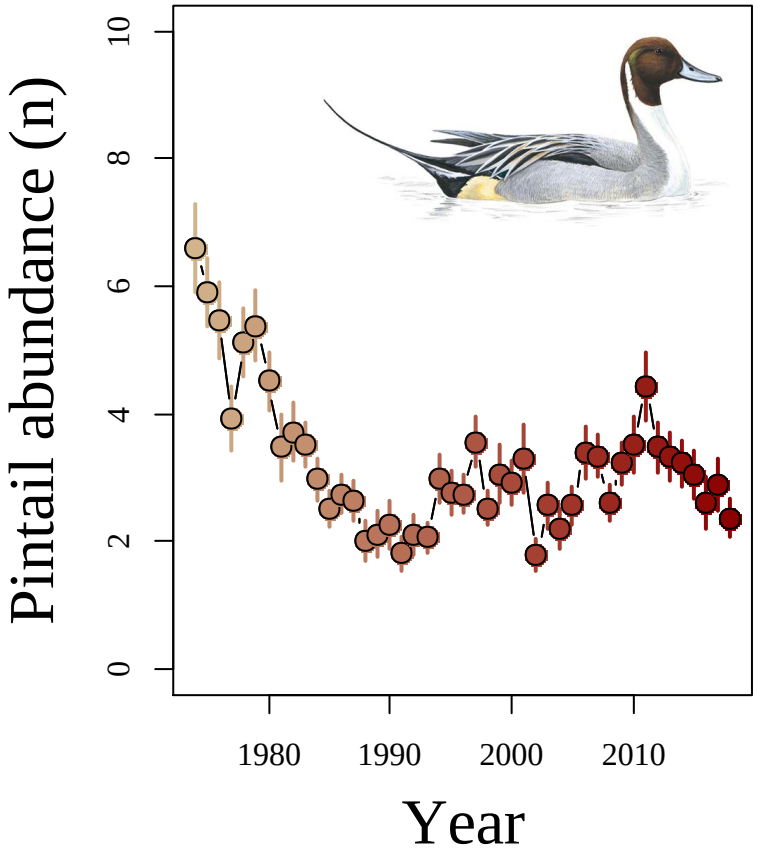
Two (patently ridiculous) motivating examples

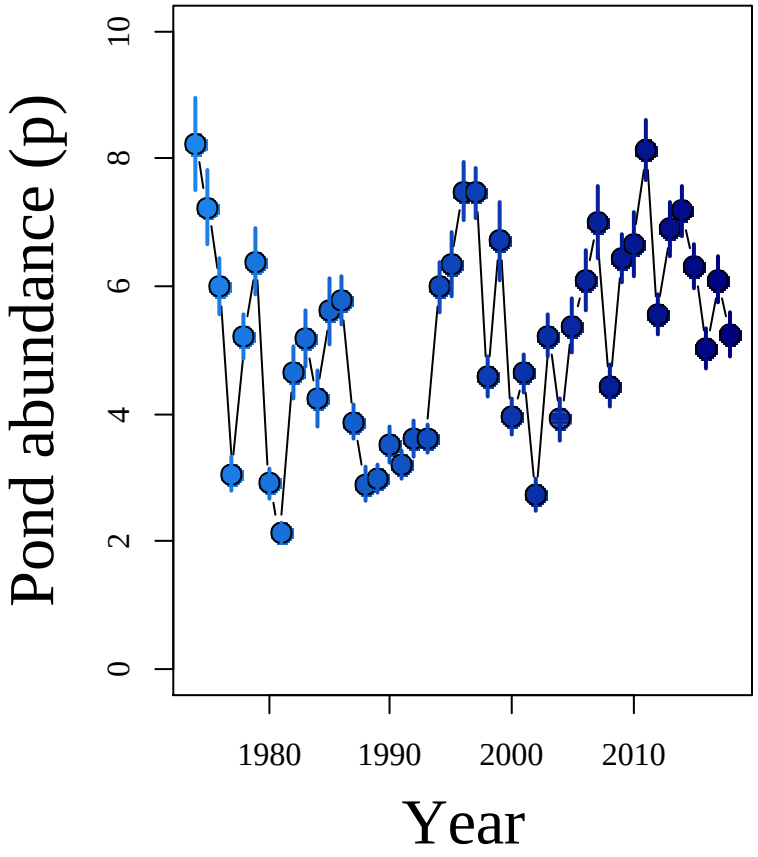
Understanding applied waterfowl management outcomes

Silly [but critically important] example 1

How many ducks will we shoot if we do ‘*X*’?

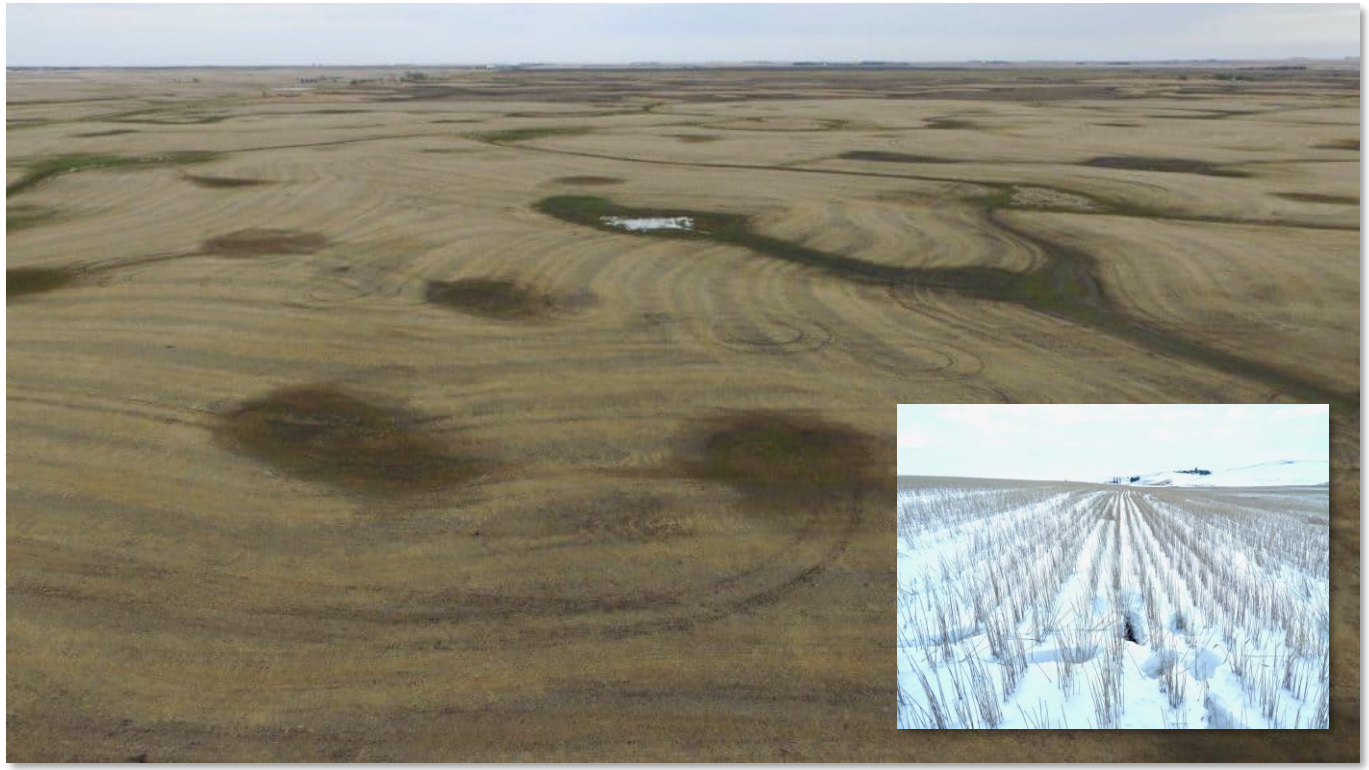
Northern pintails are relatively unique among dabbling ducks



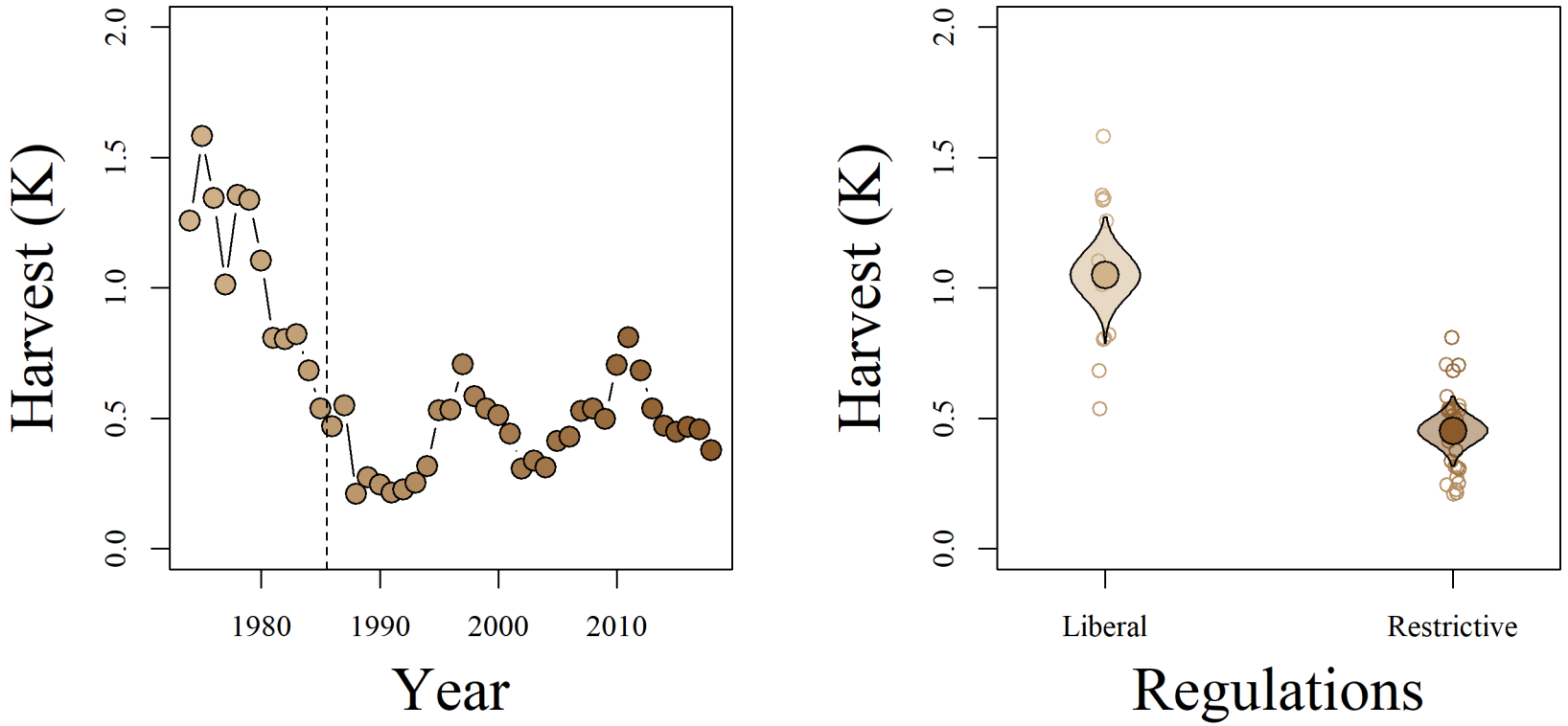


Like other ducks, they like ponds, but haven’t done as well…

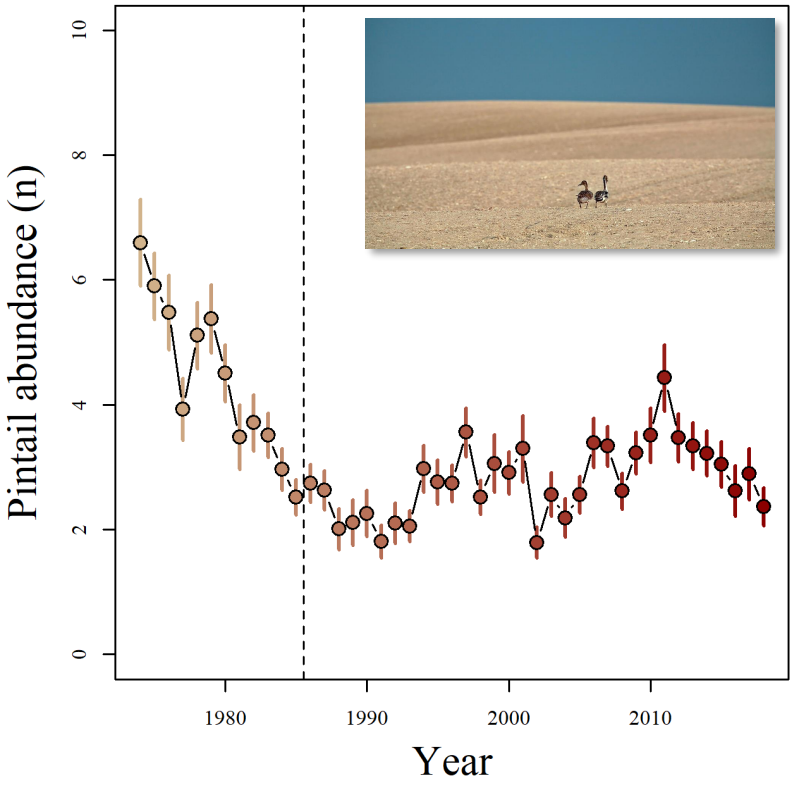
A textbook example of an ‘ecological trap’

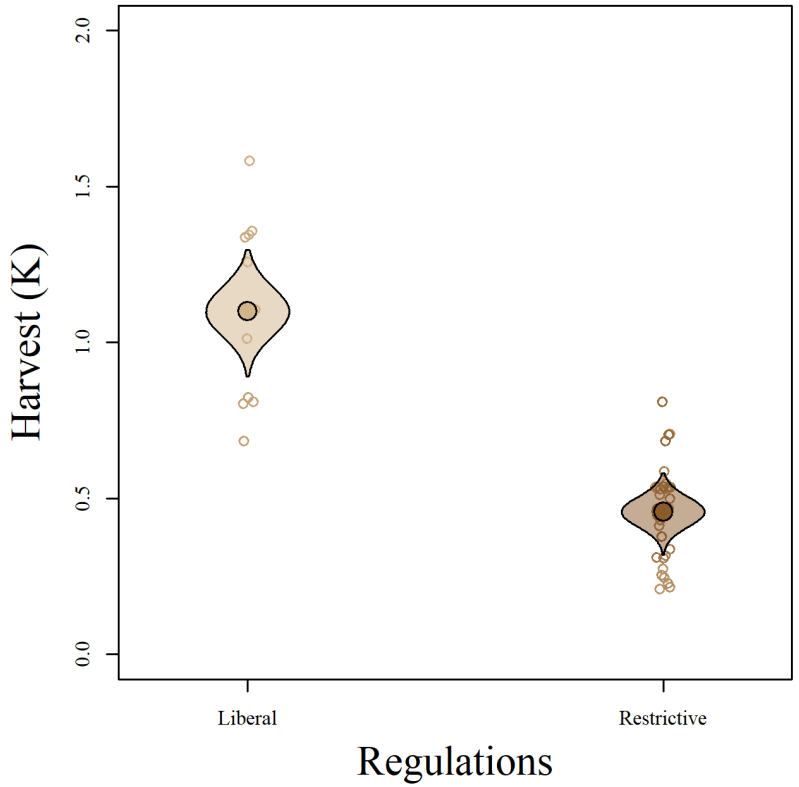


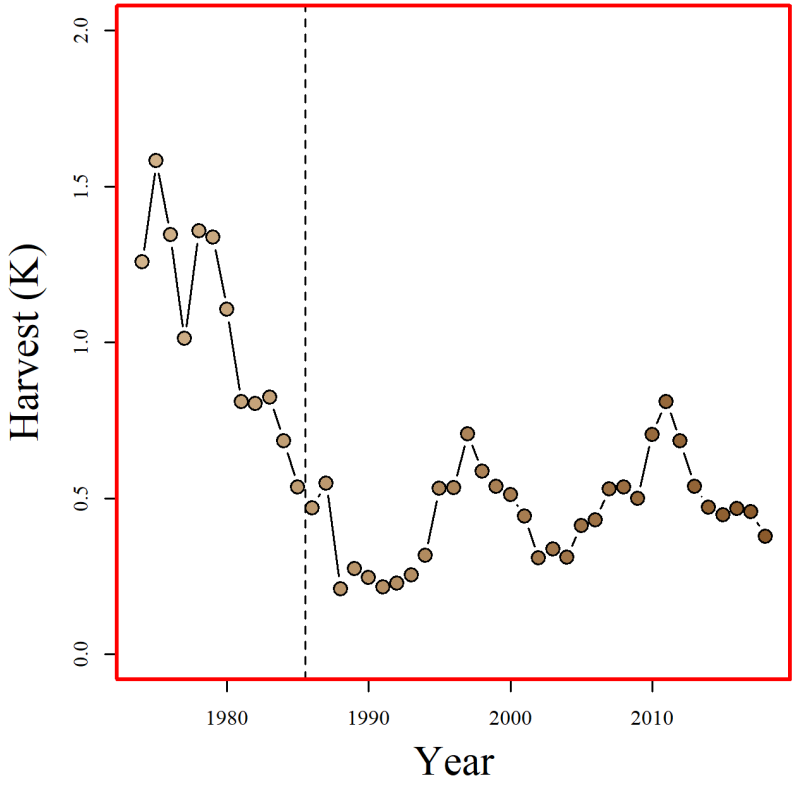
Harvest management has been ‘our’ main response…



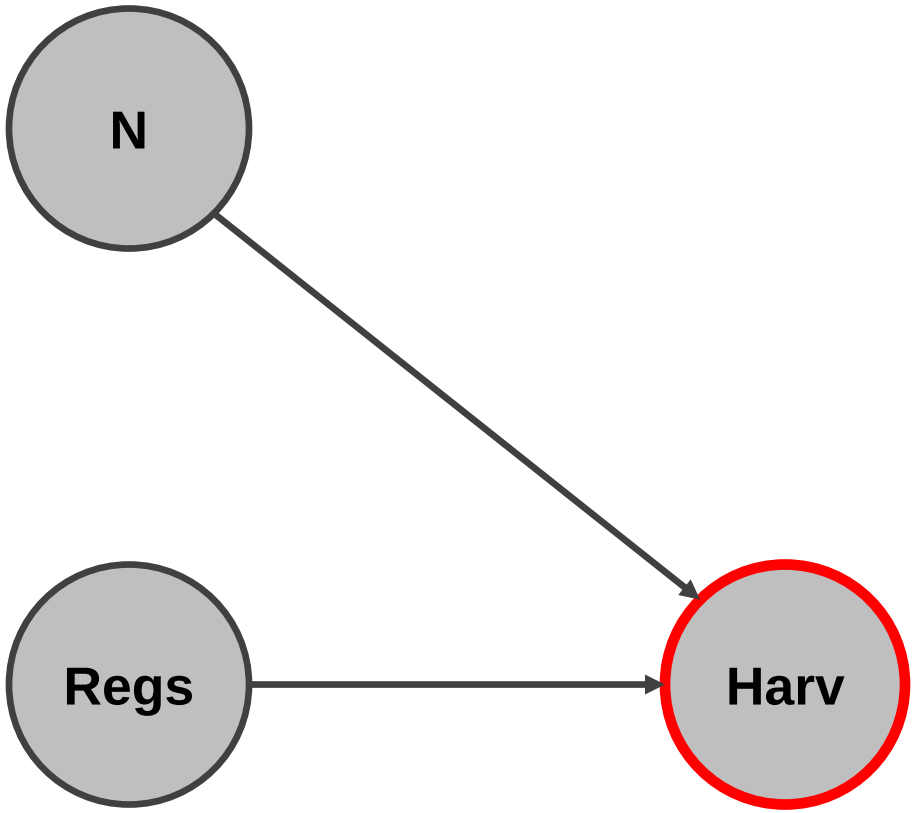
We’ve reached an impasse… 40 years of no results







Let's build a better model…

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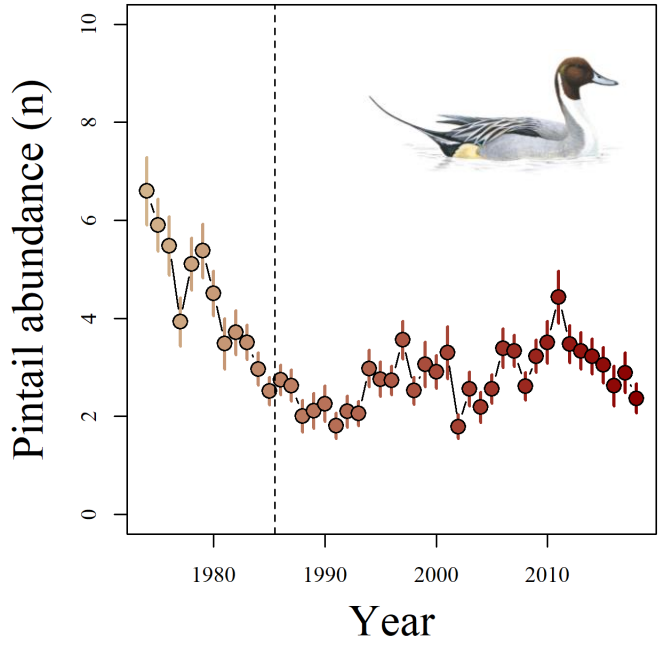
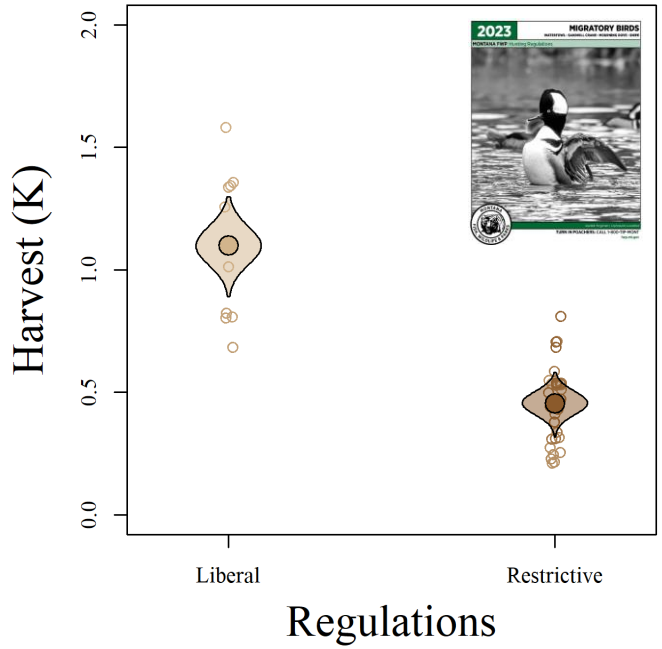
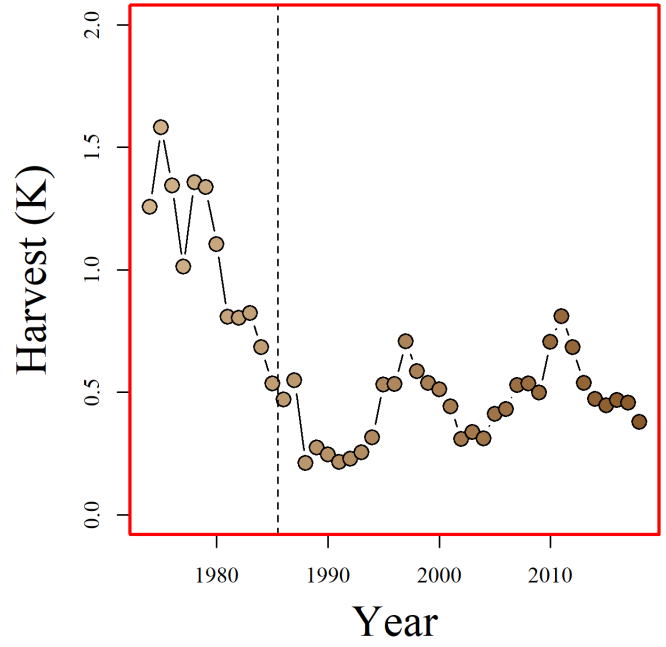
glm(K ~ R + N)
```







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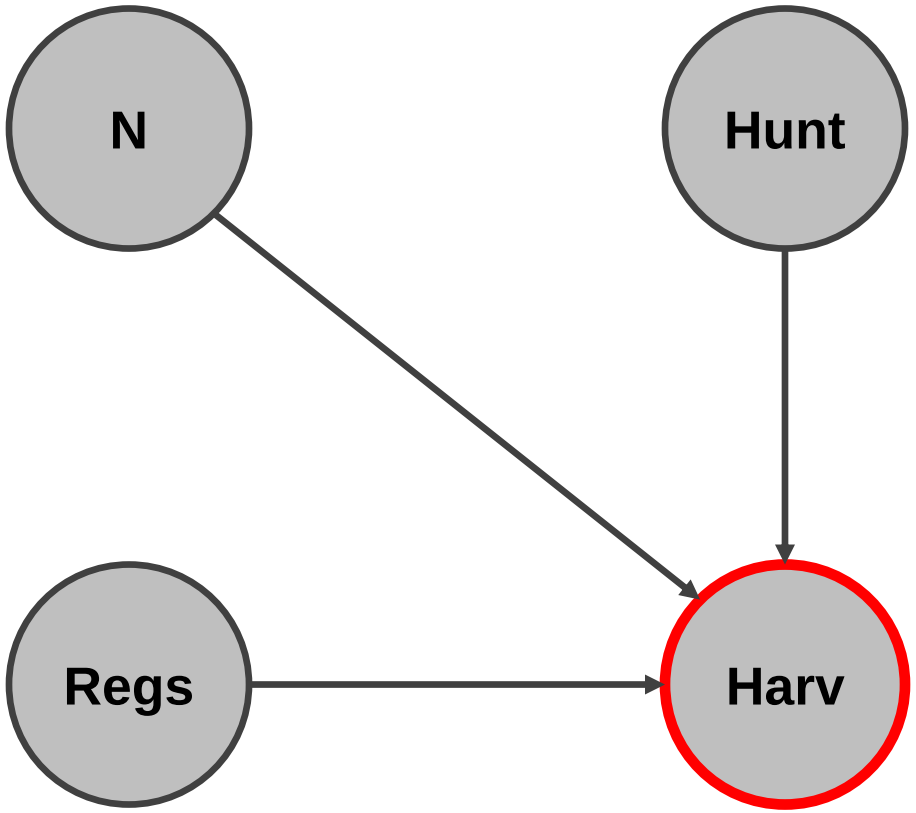


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glm(K ~ R + N + H)
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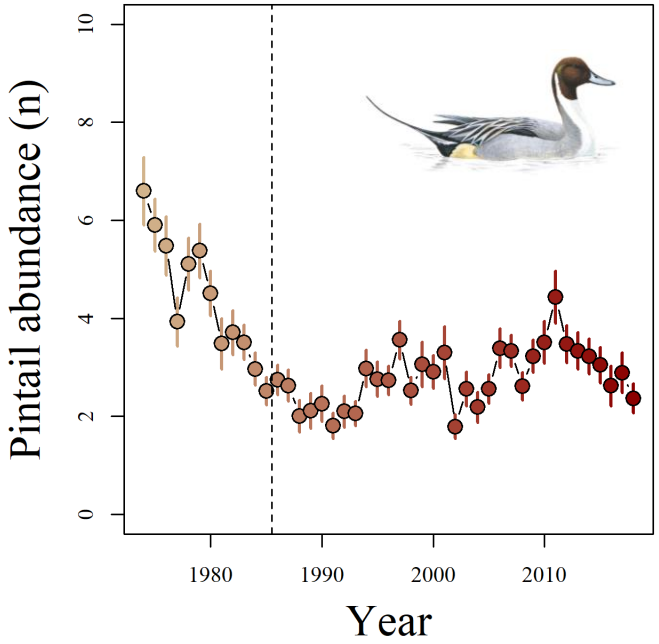
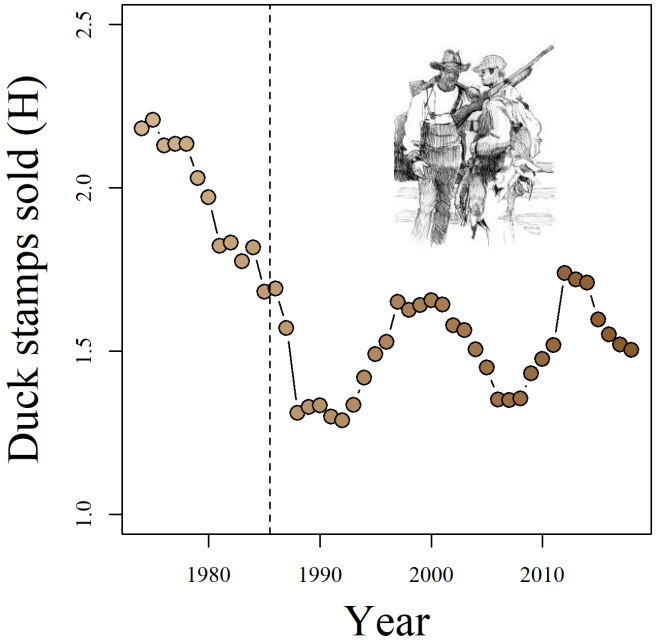
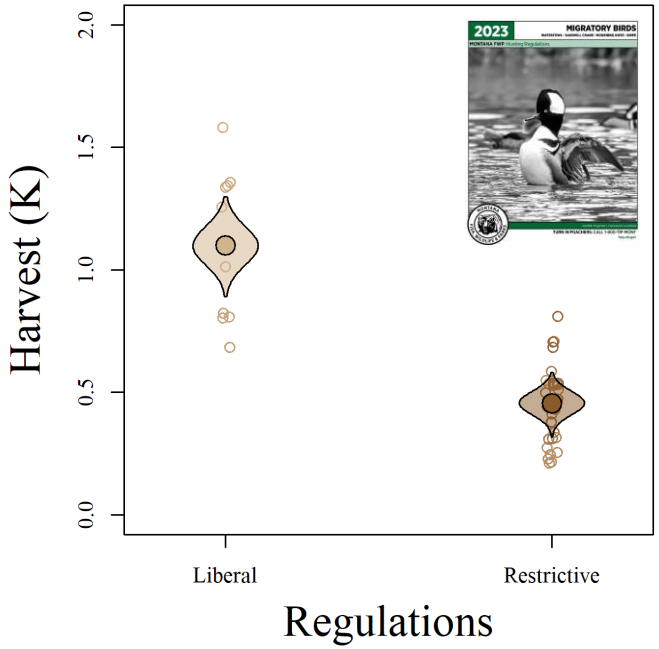
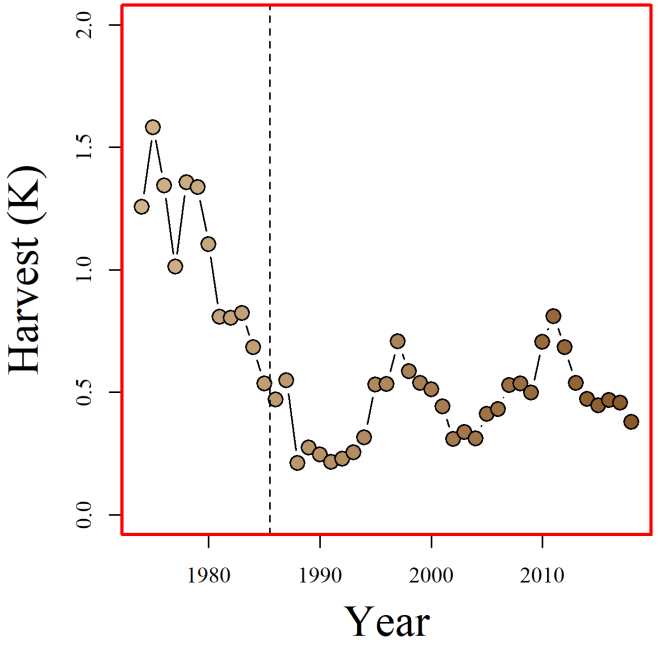
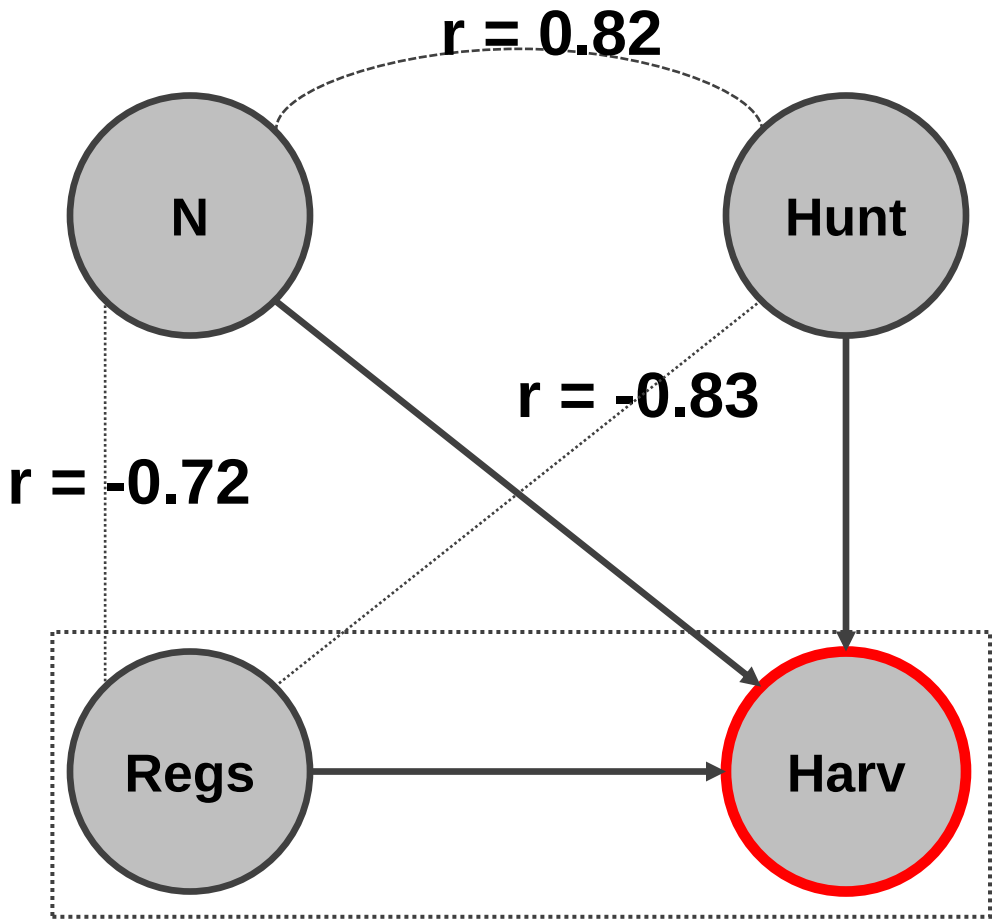




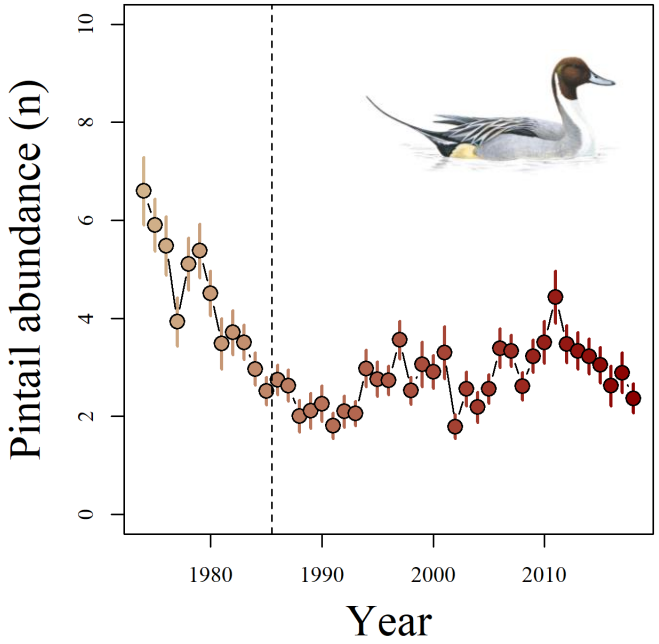


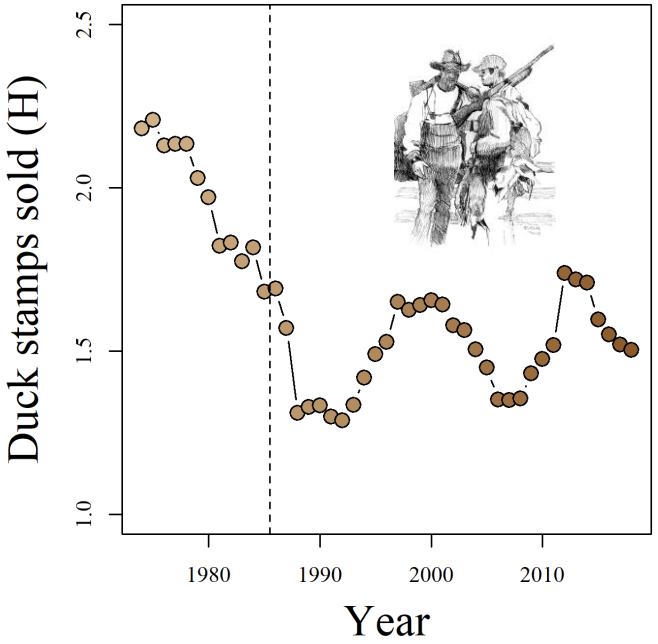


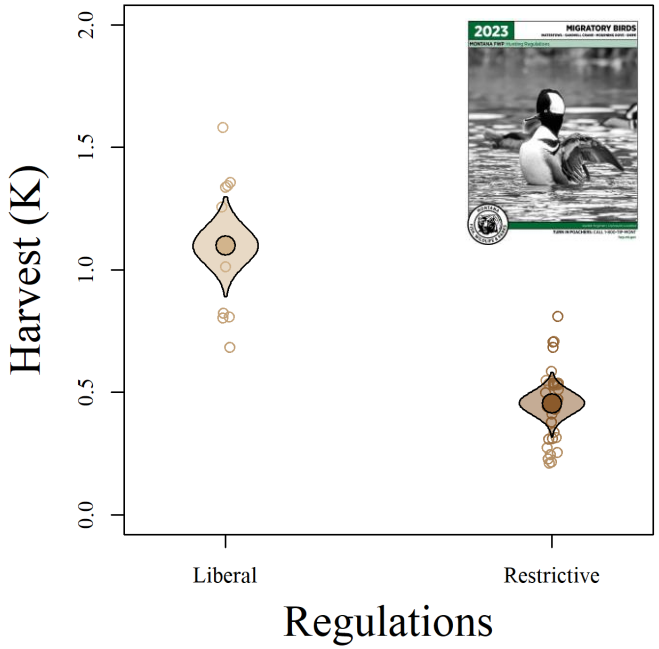
Let's build a better model…

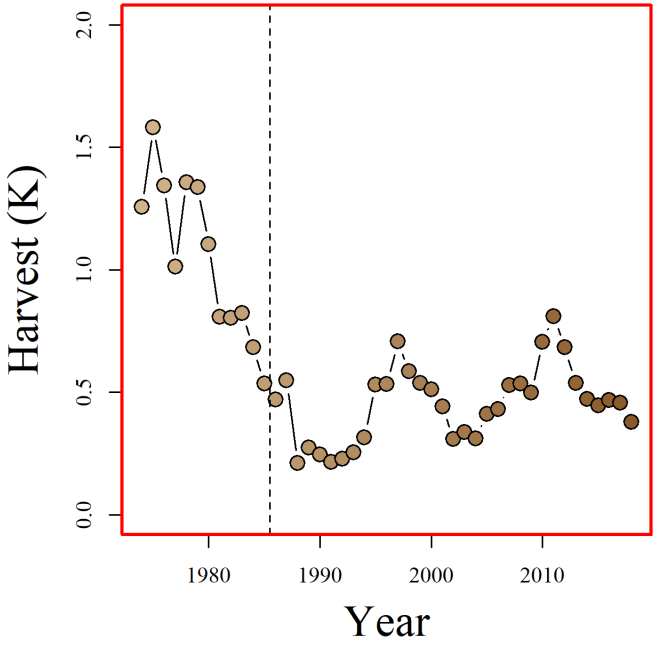



```
glm(K ~ R + N + H)
```

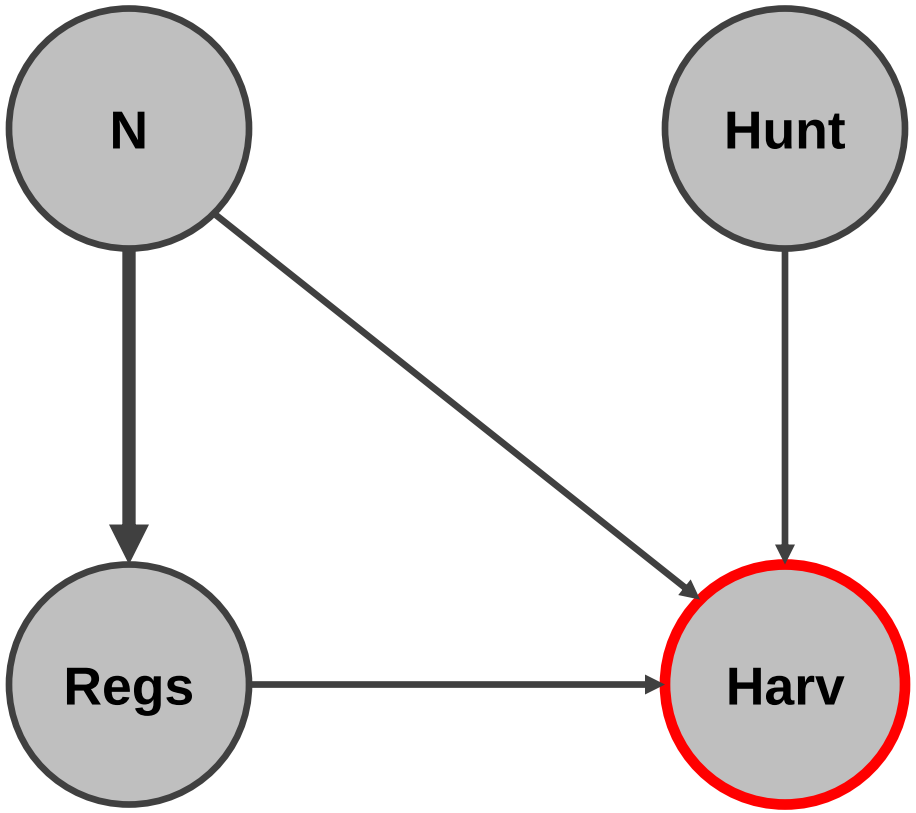


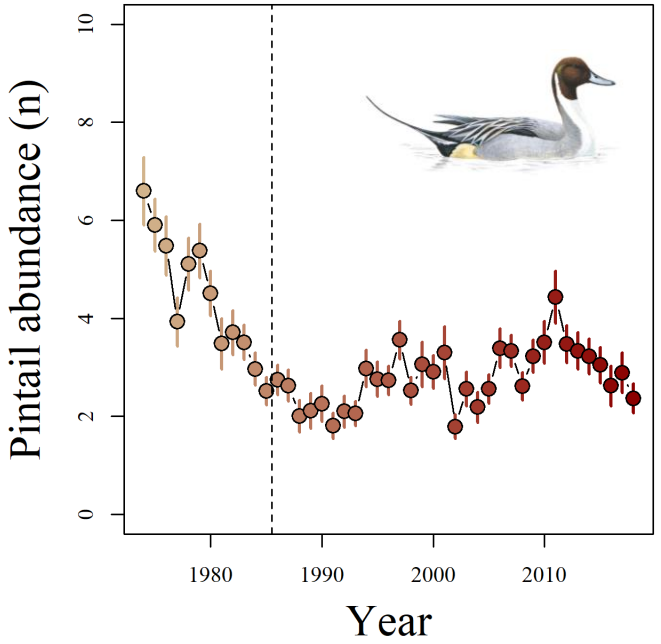


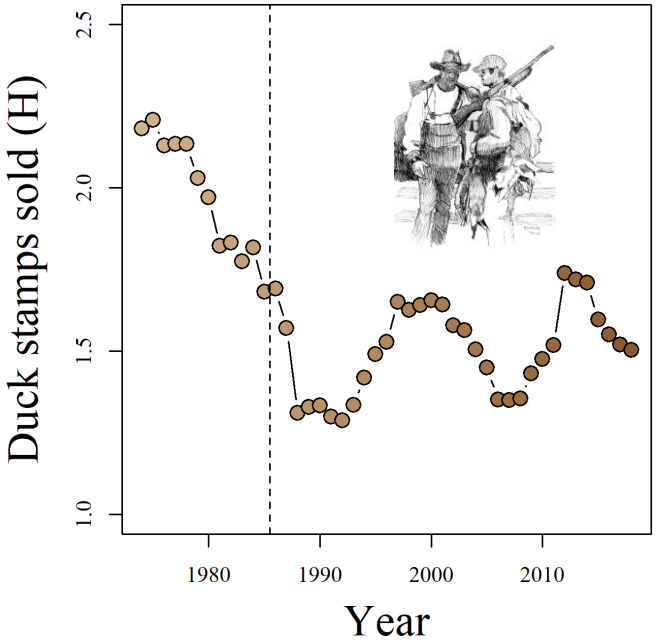


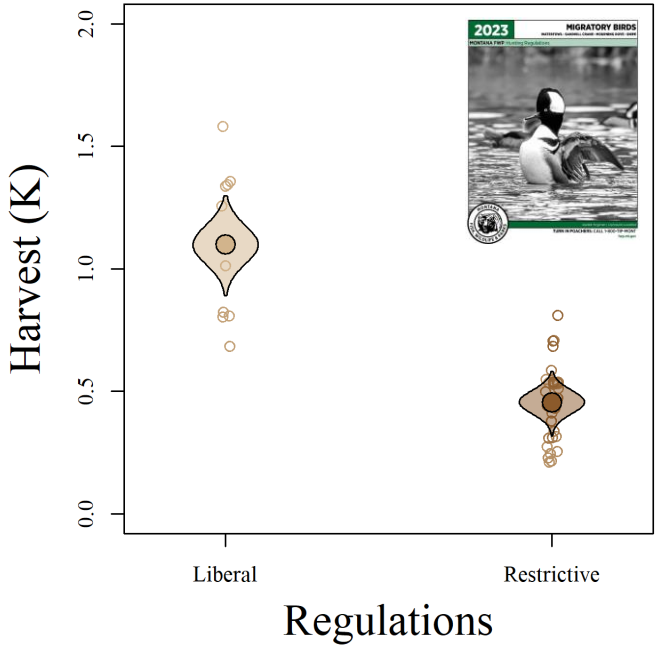


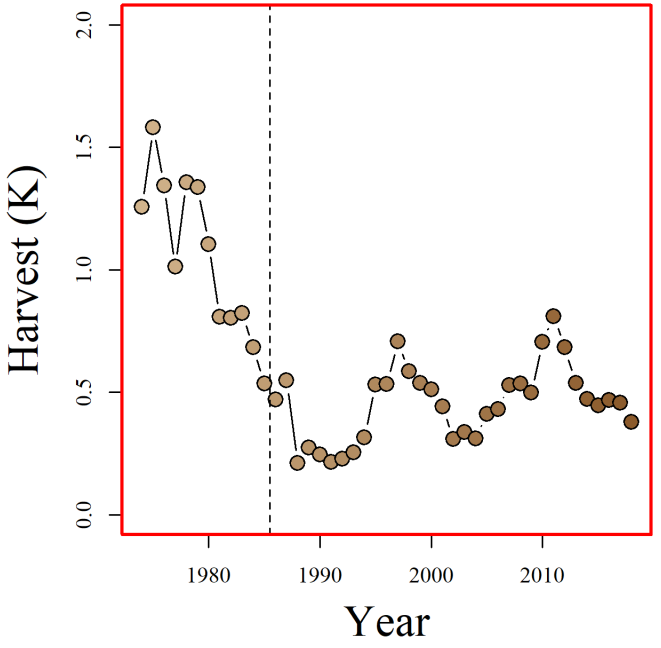
Let's build a better model…



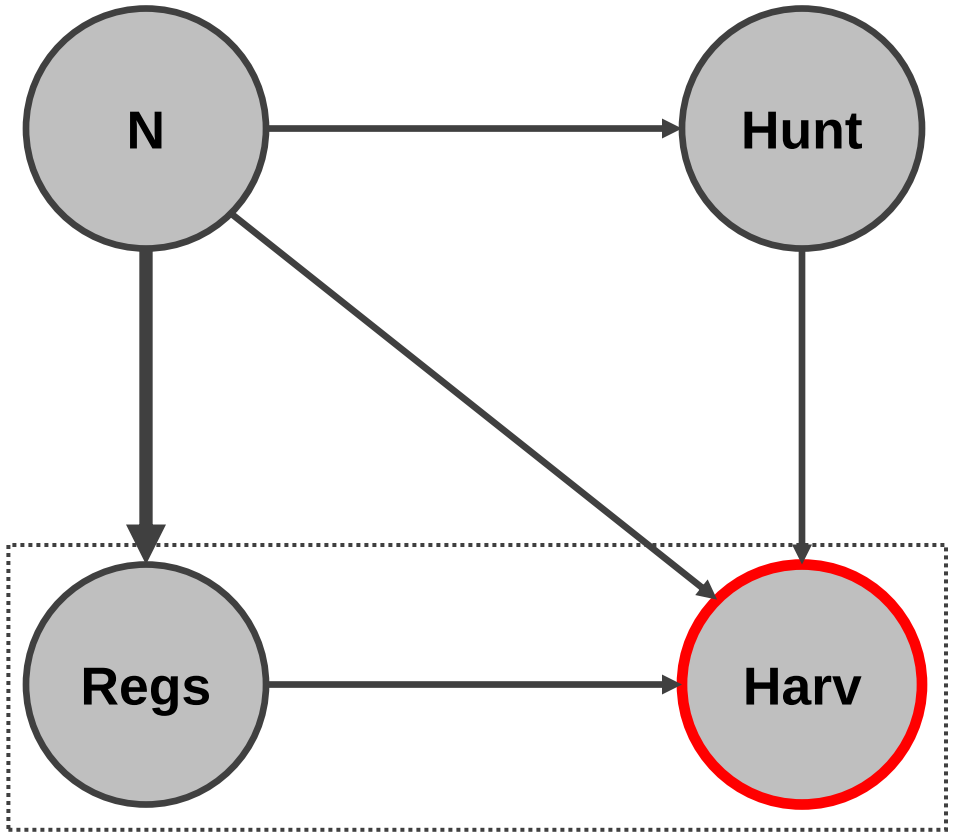


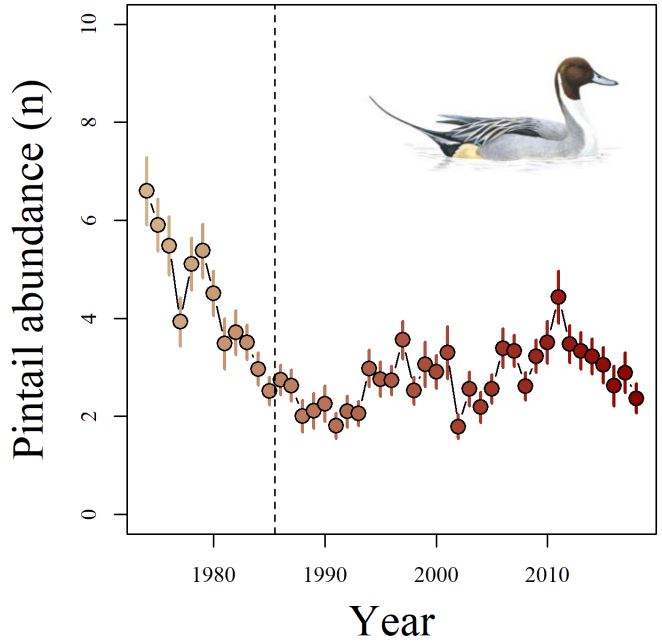


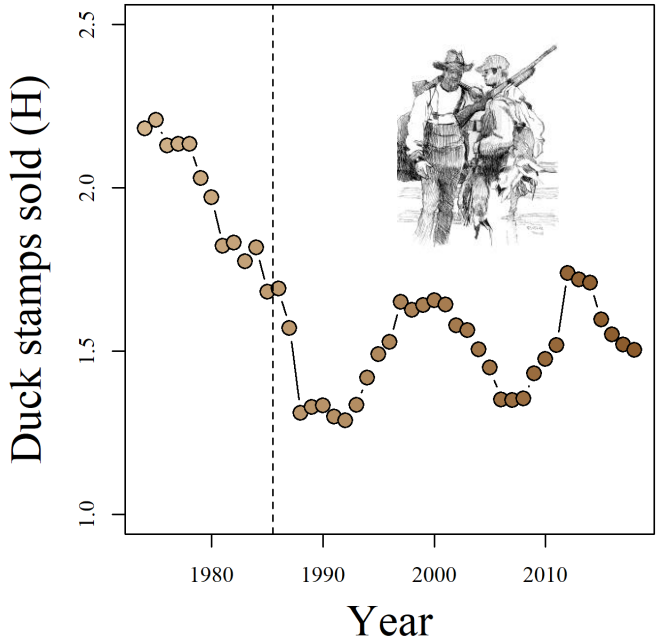


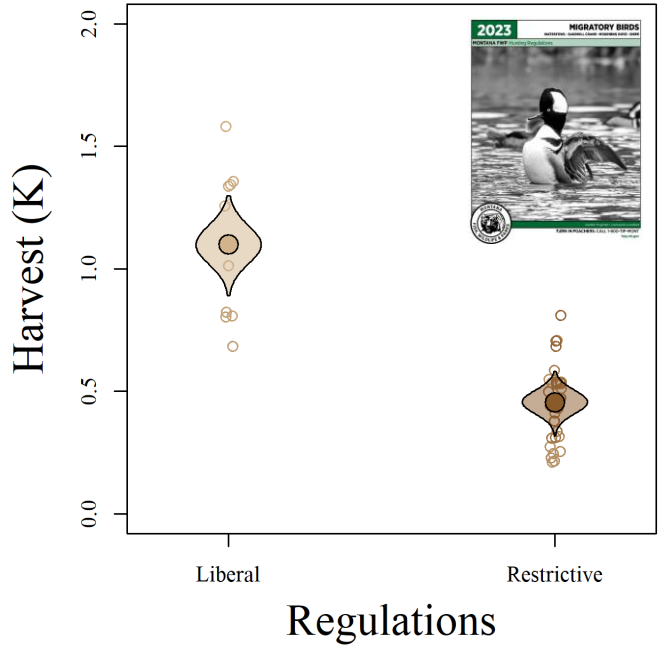


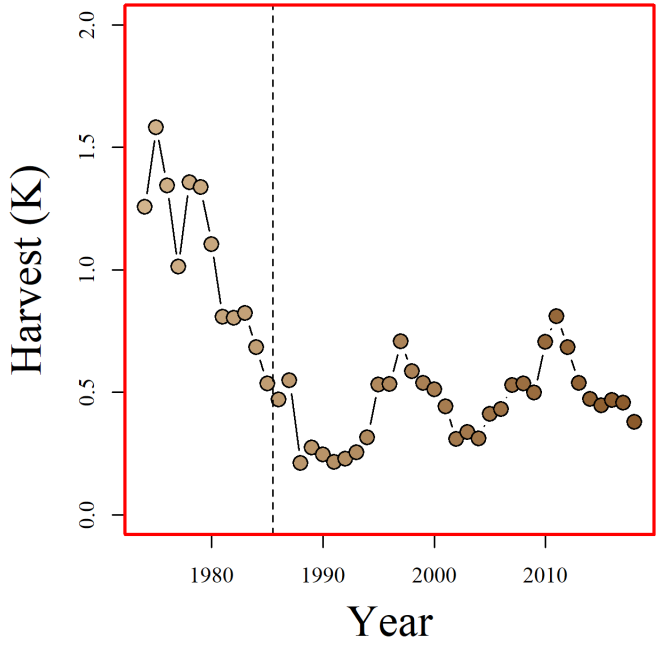
A better model…



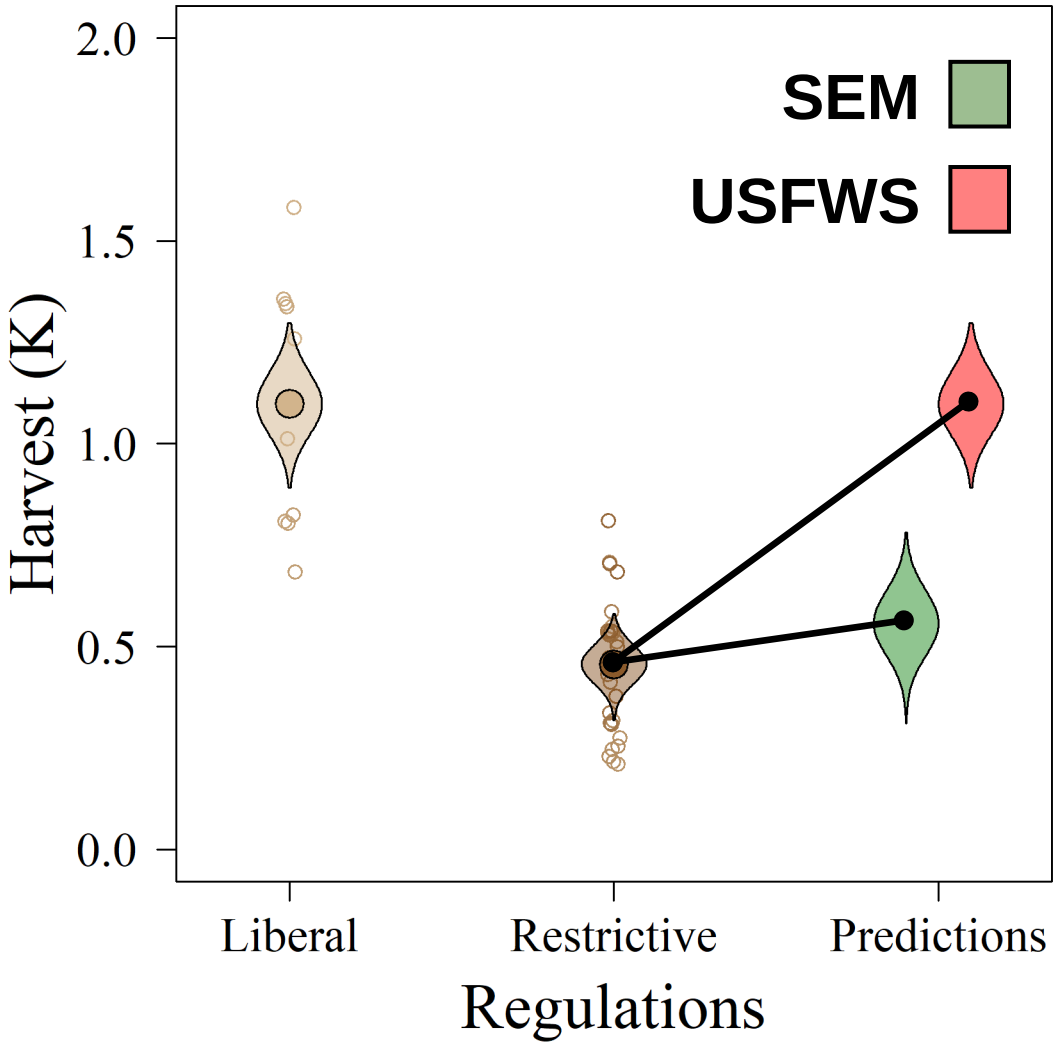


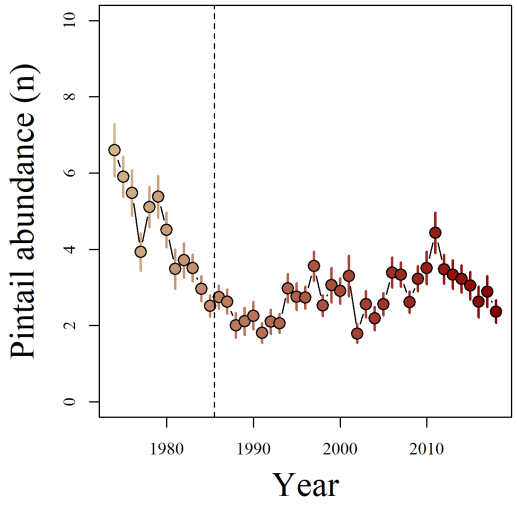


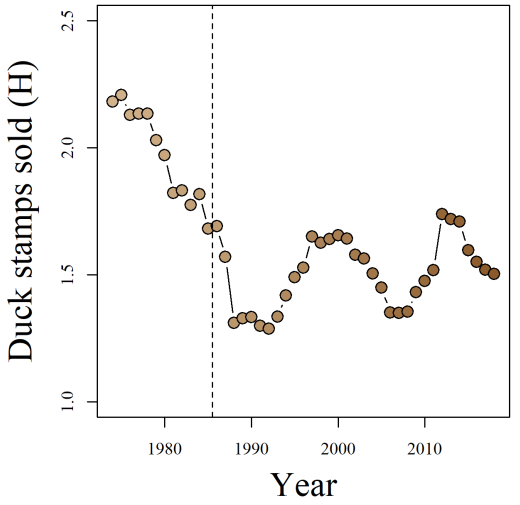


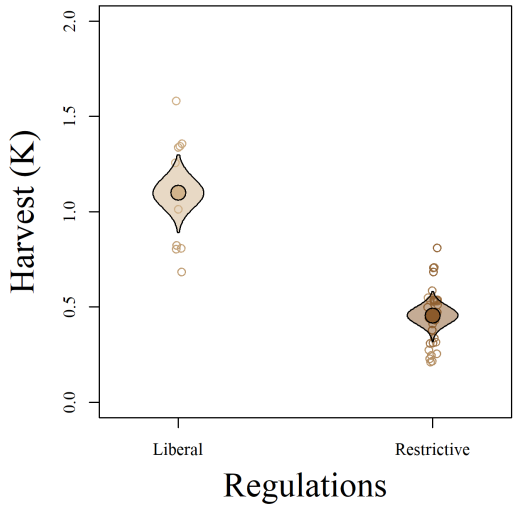


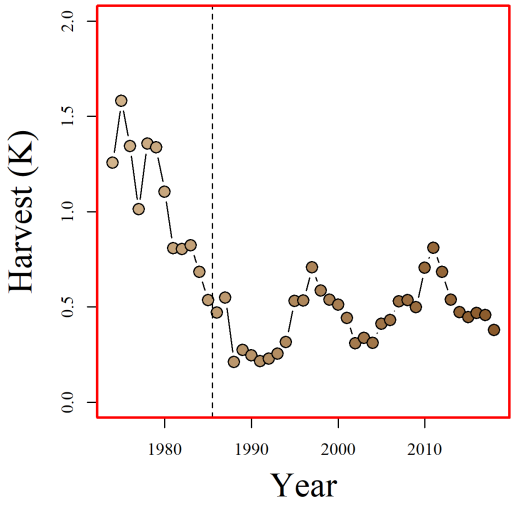
Two models, wildly different conclusions…



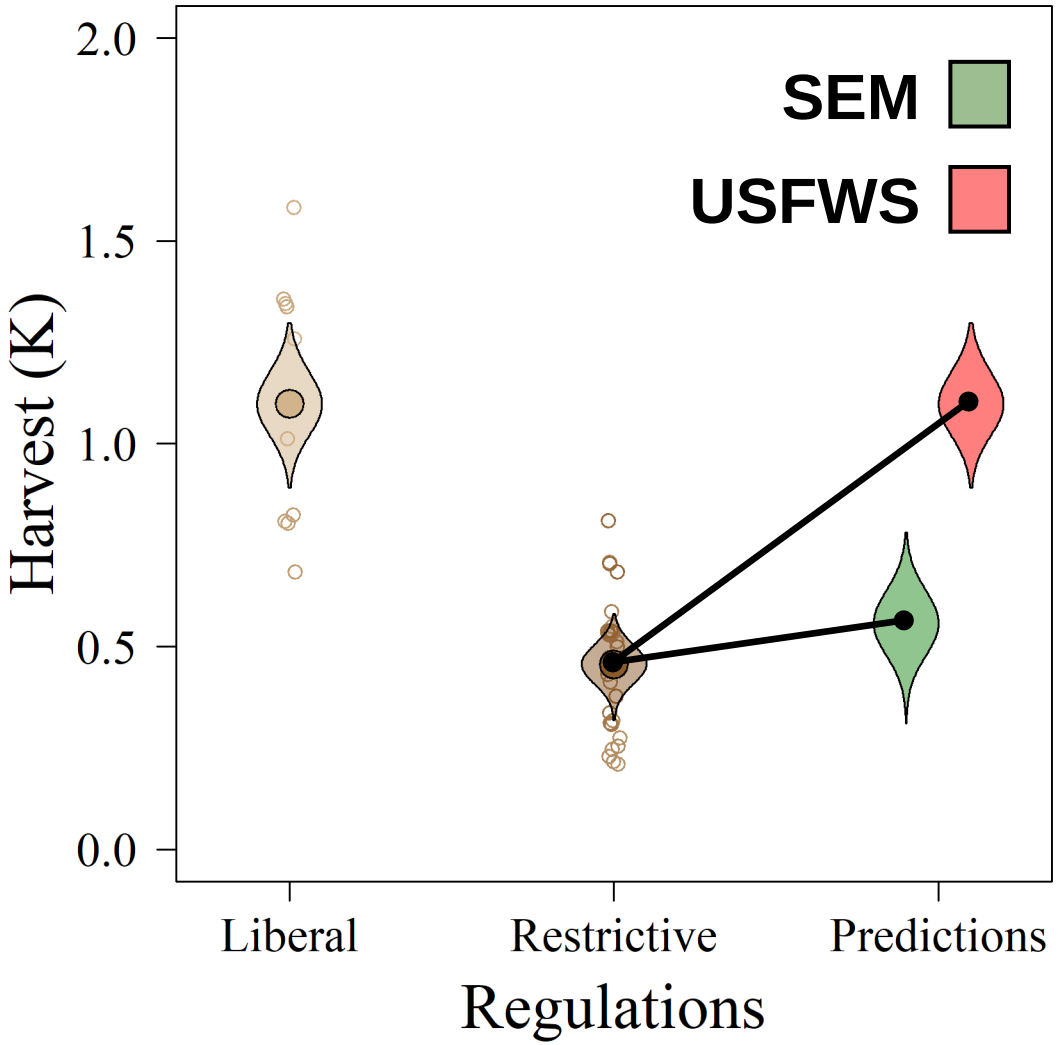


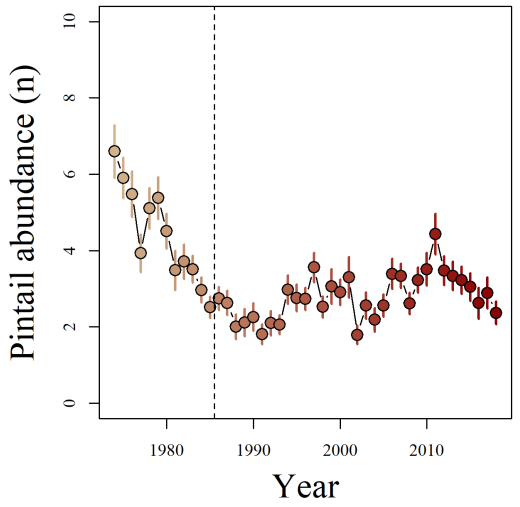


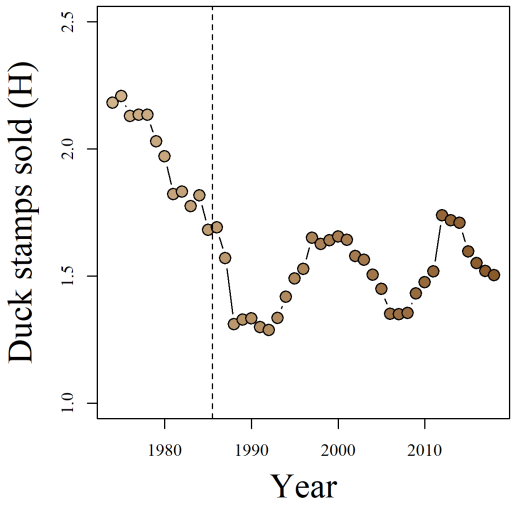


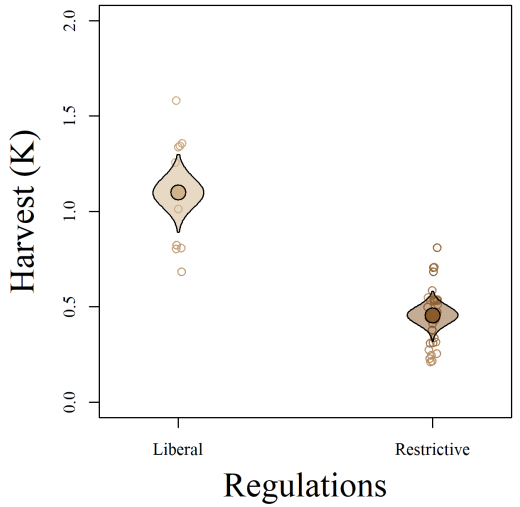


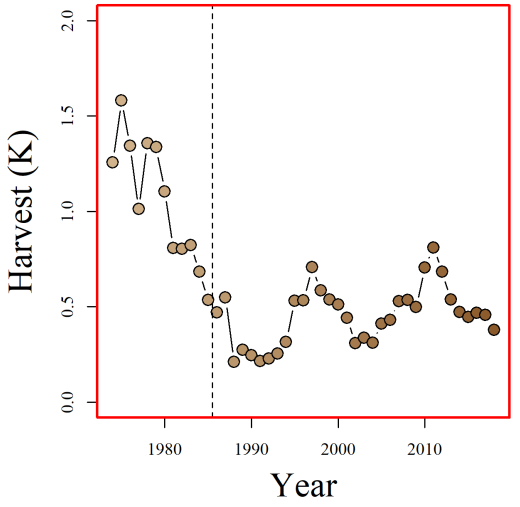
The USFWS just decided to do something similar







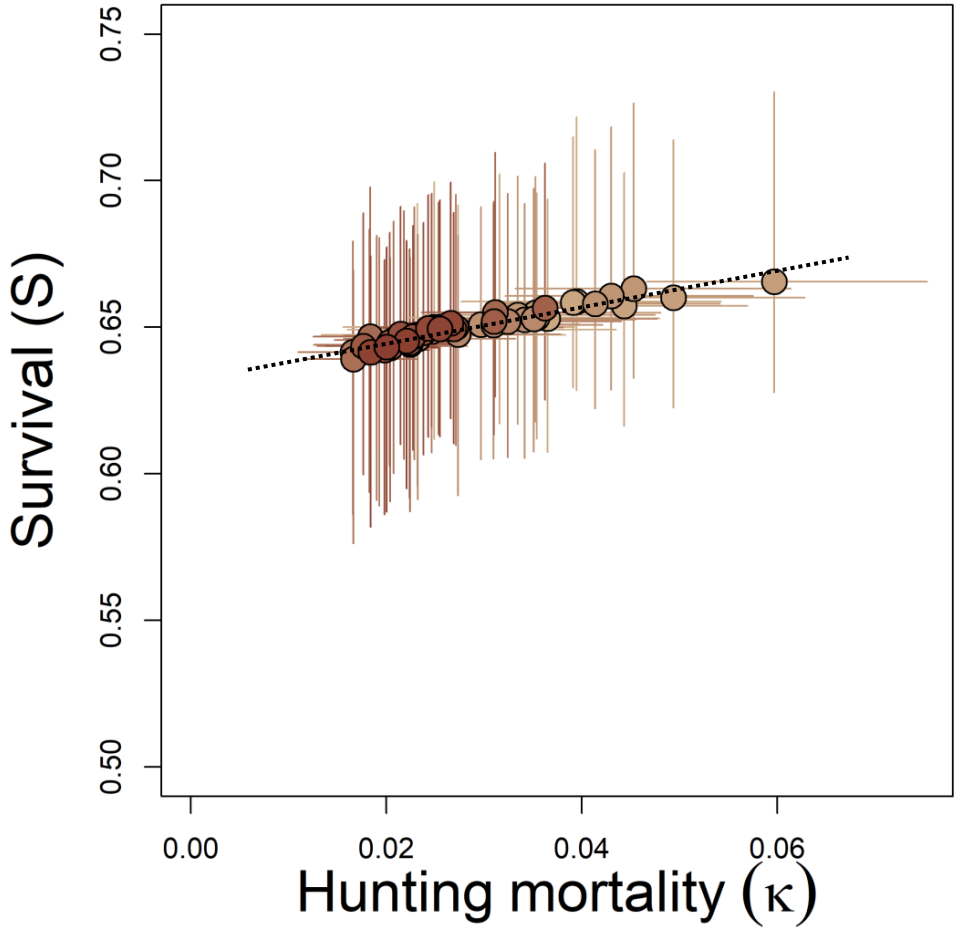


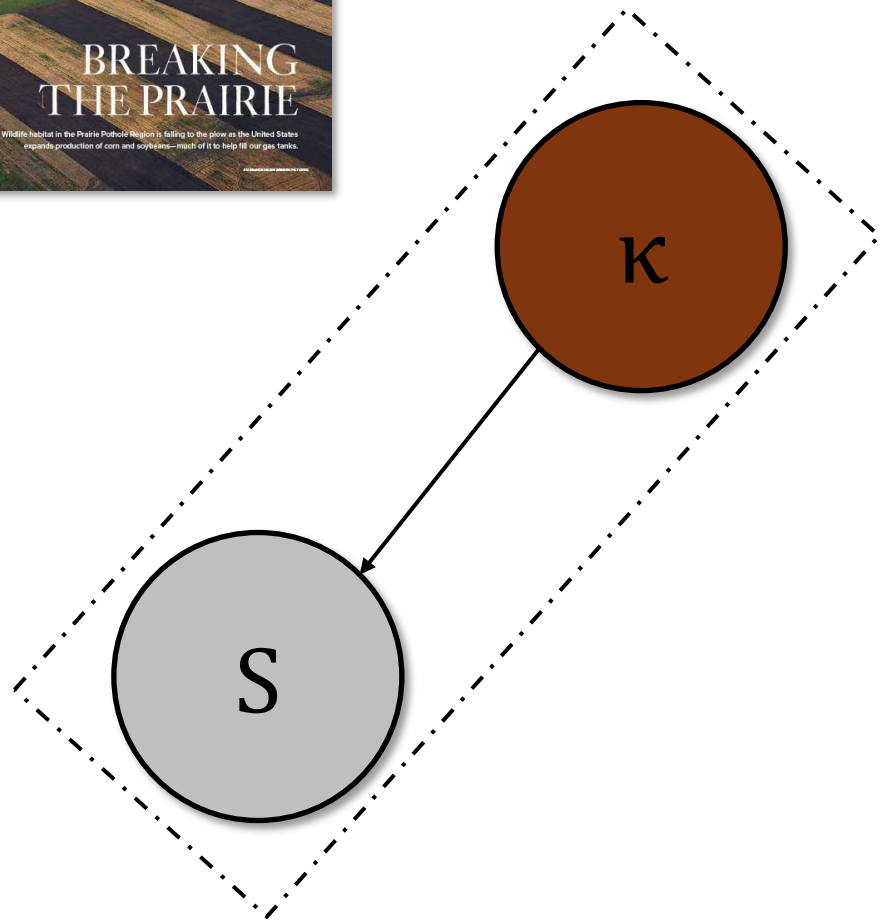


Silly [but critically important] example 2

What is the effect of hunting on survival?

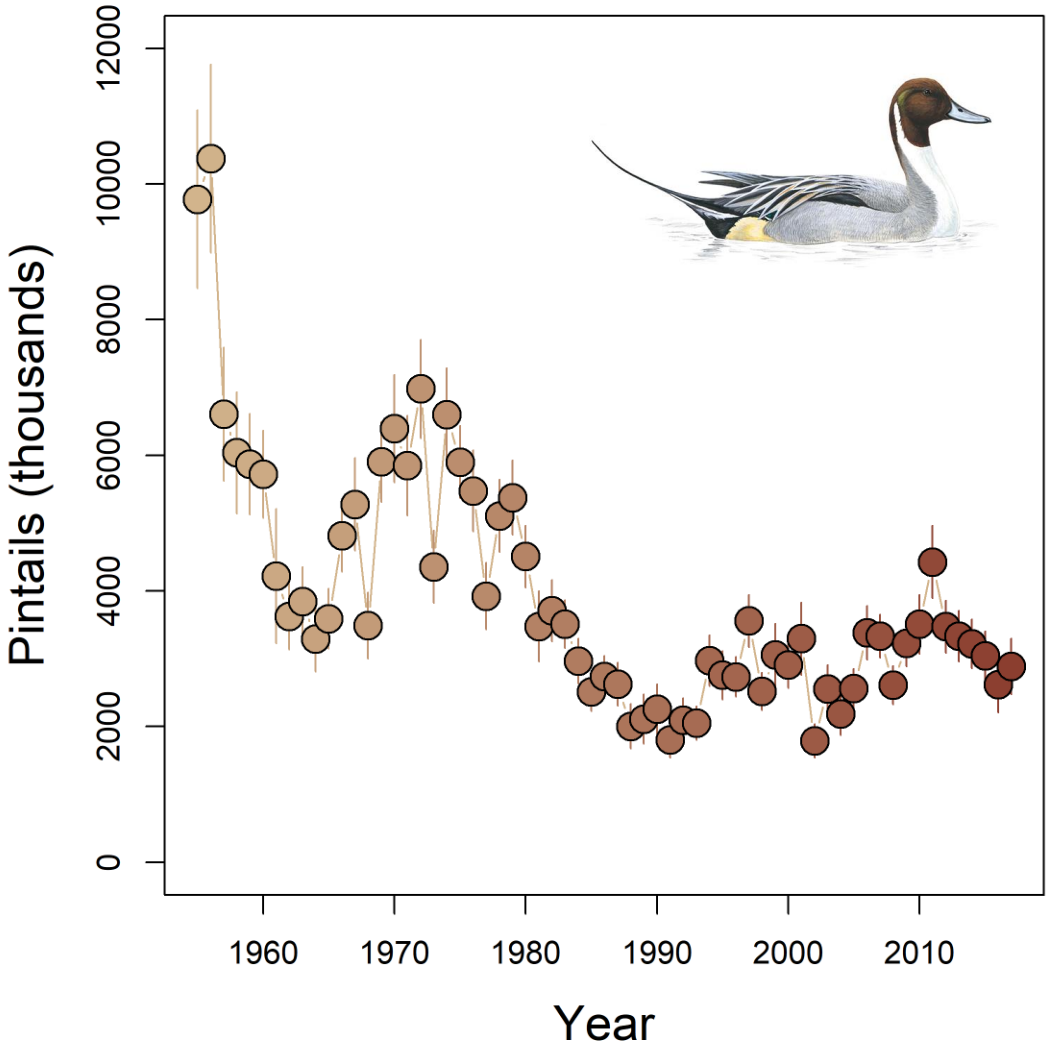
How does this happen?



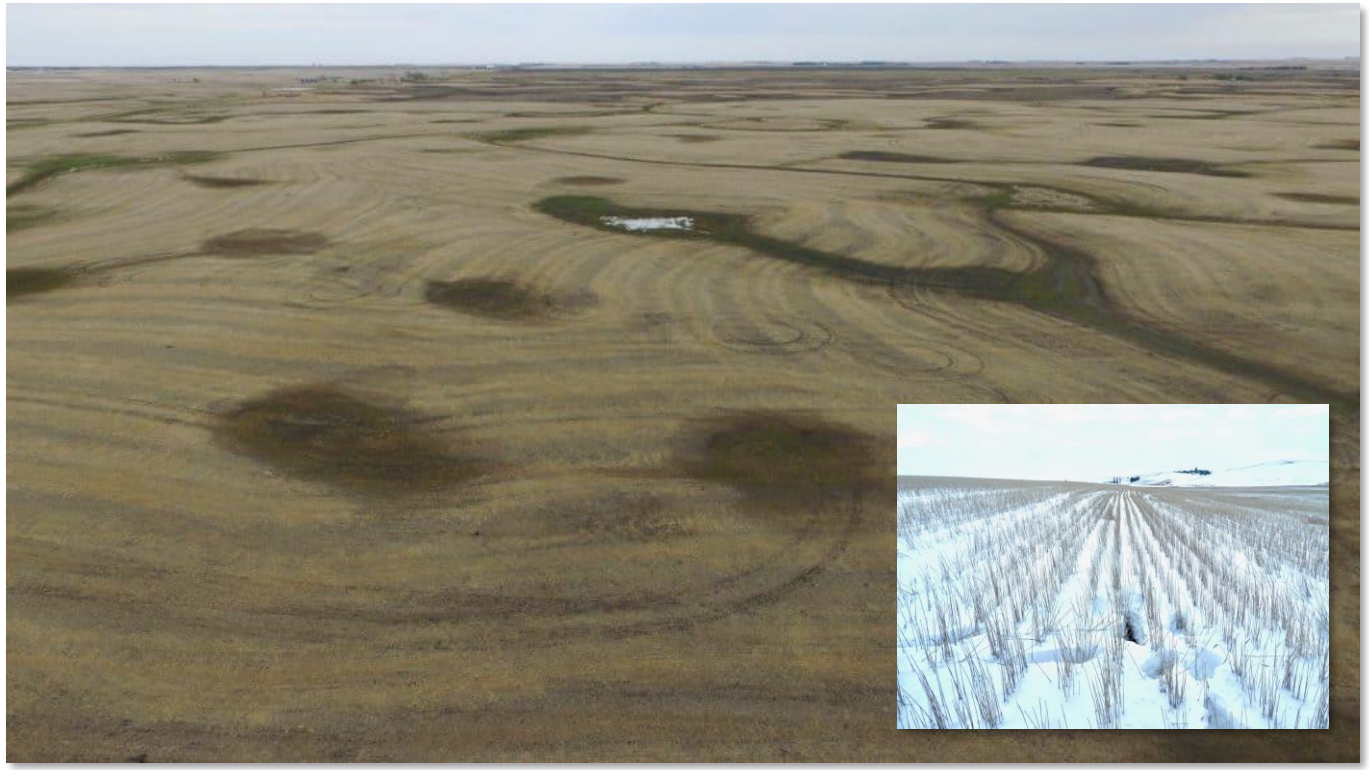


Every hunter killed hen means 2 more survive?!

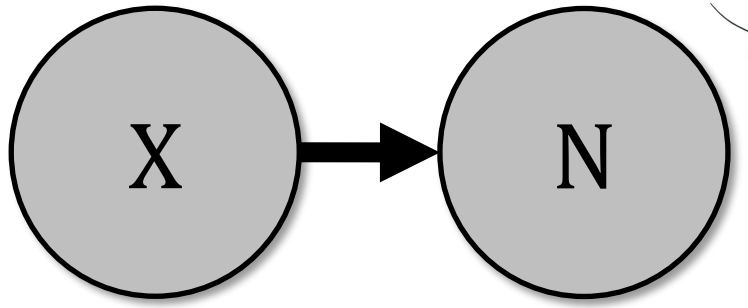
Pintail populations have crashed

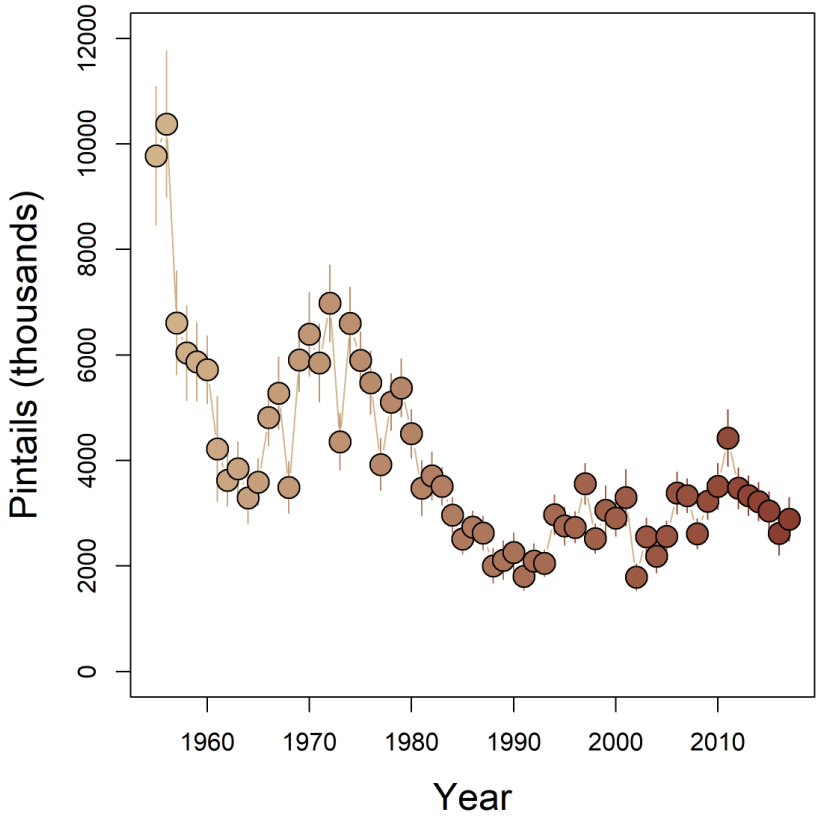


A textbook example of an ‘ecological trap’

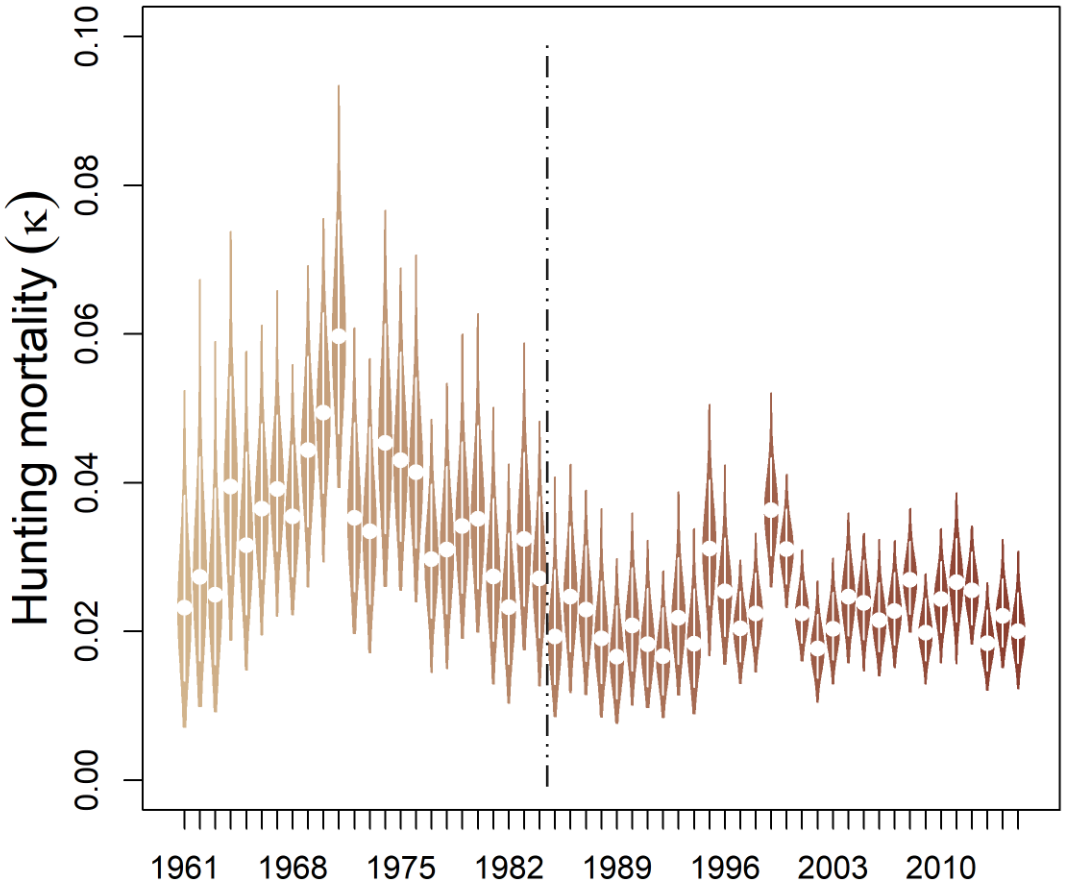


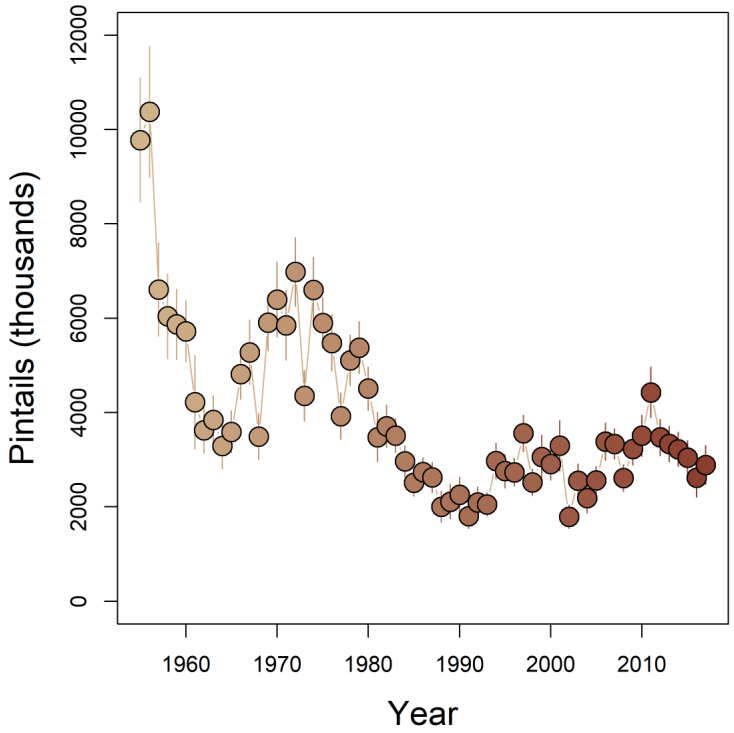
Habitat changes led to declines





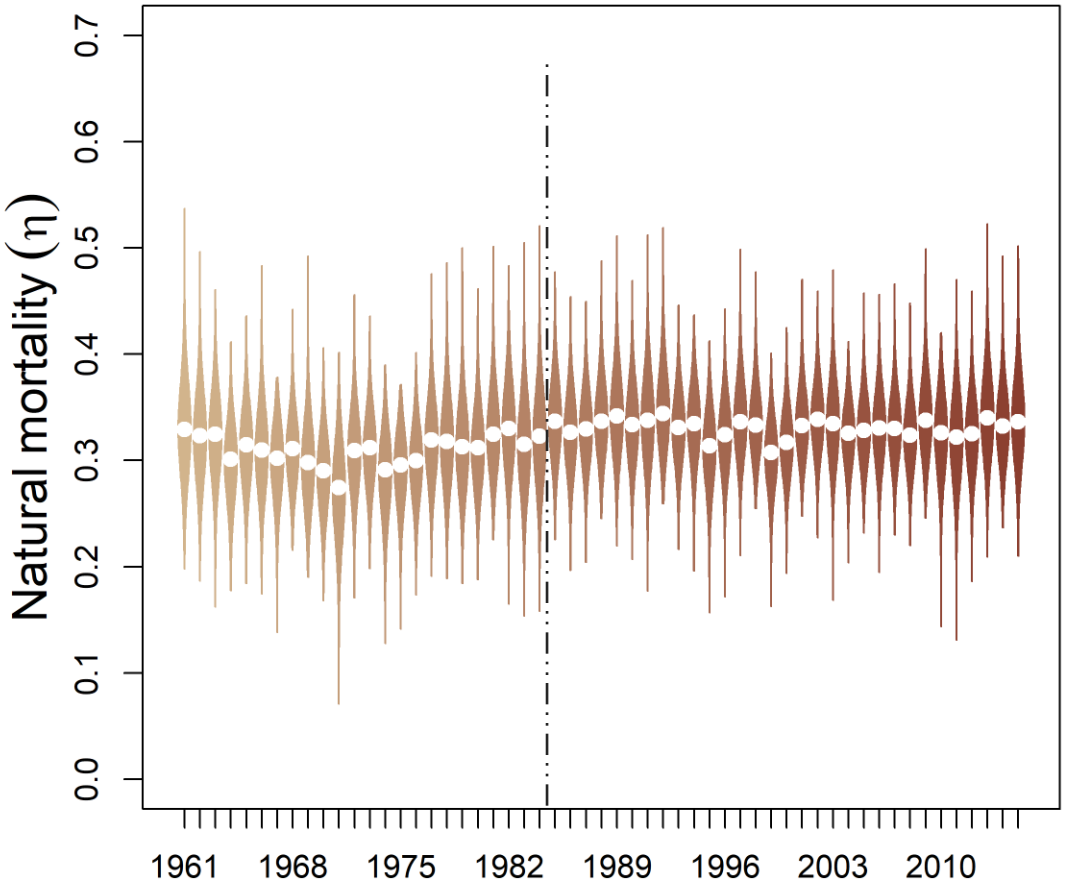
Declines led to restrictive regulations

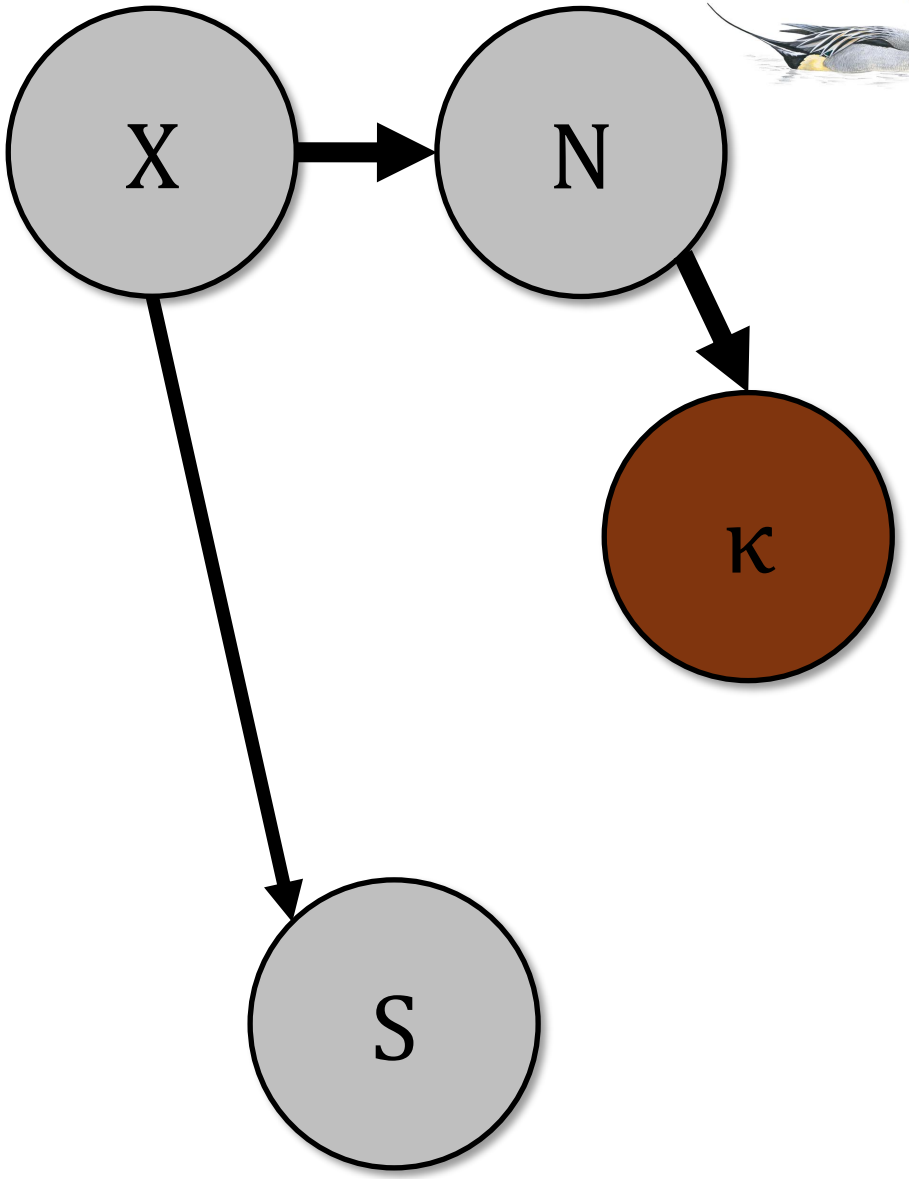




Long-term ecosystem change (and potentially harvest to some degree?) drove populations down, restrictive regs followed

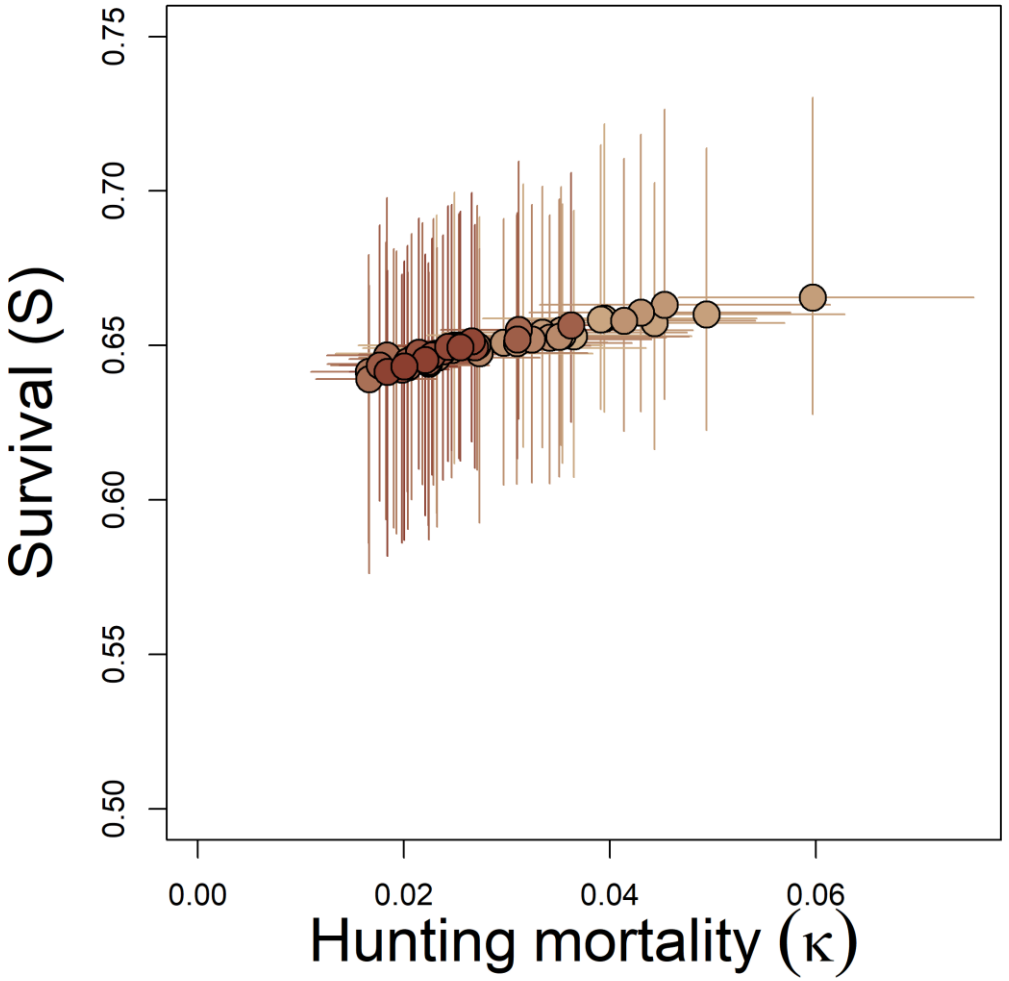
Habitat changes also affected survival!

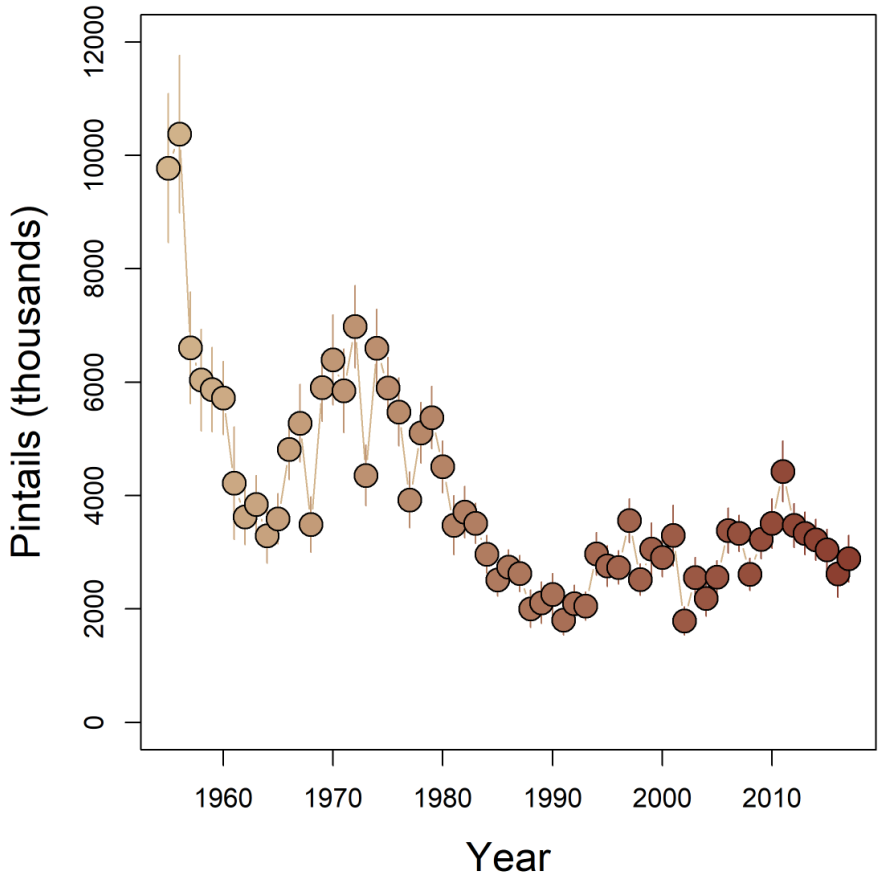




Long-term ecosystem change increased natural mortality rates?

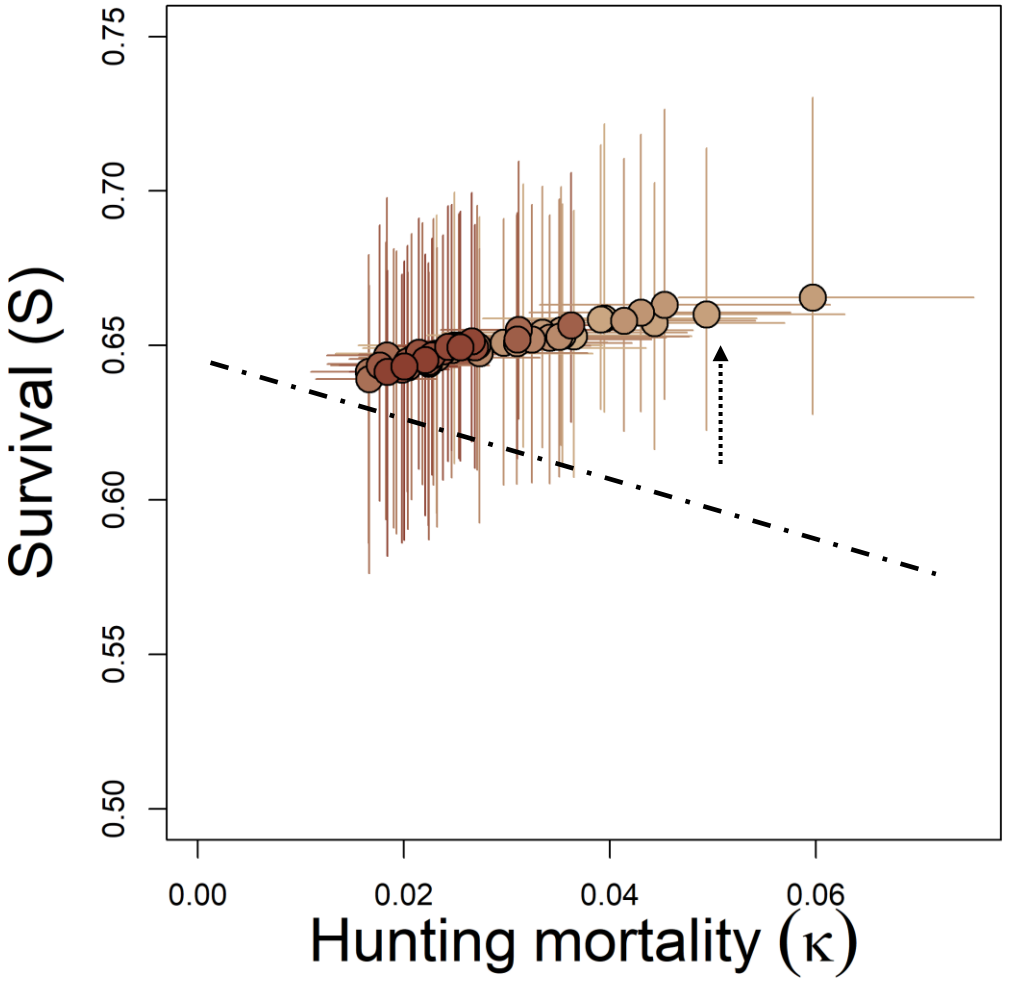
Univariate regression is insufficient

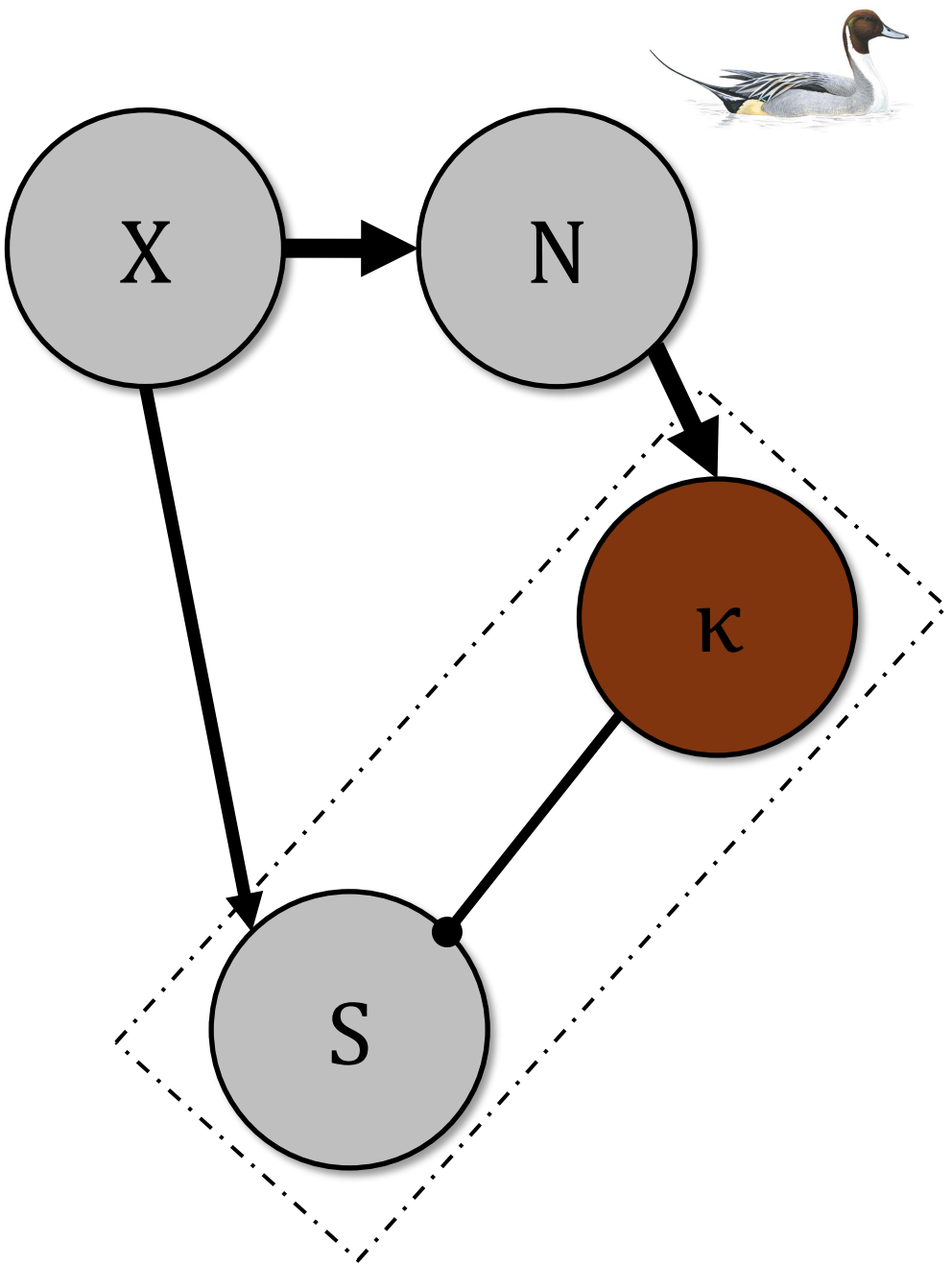




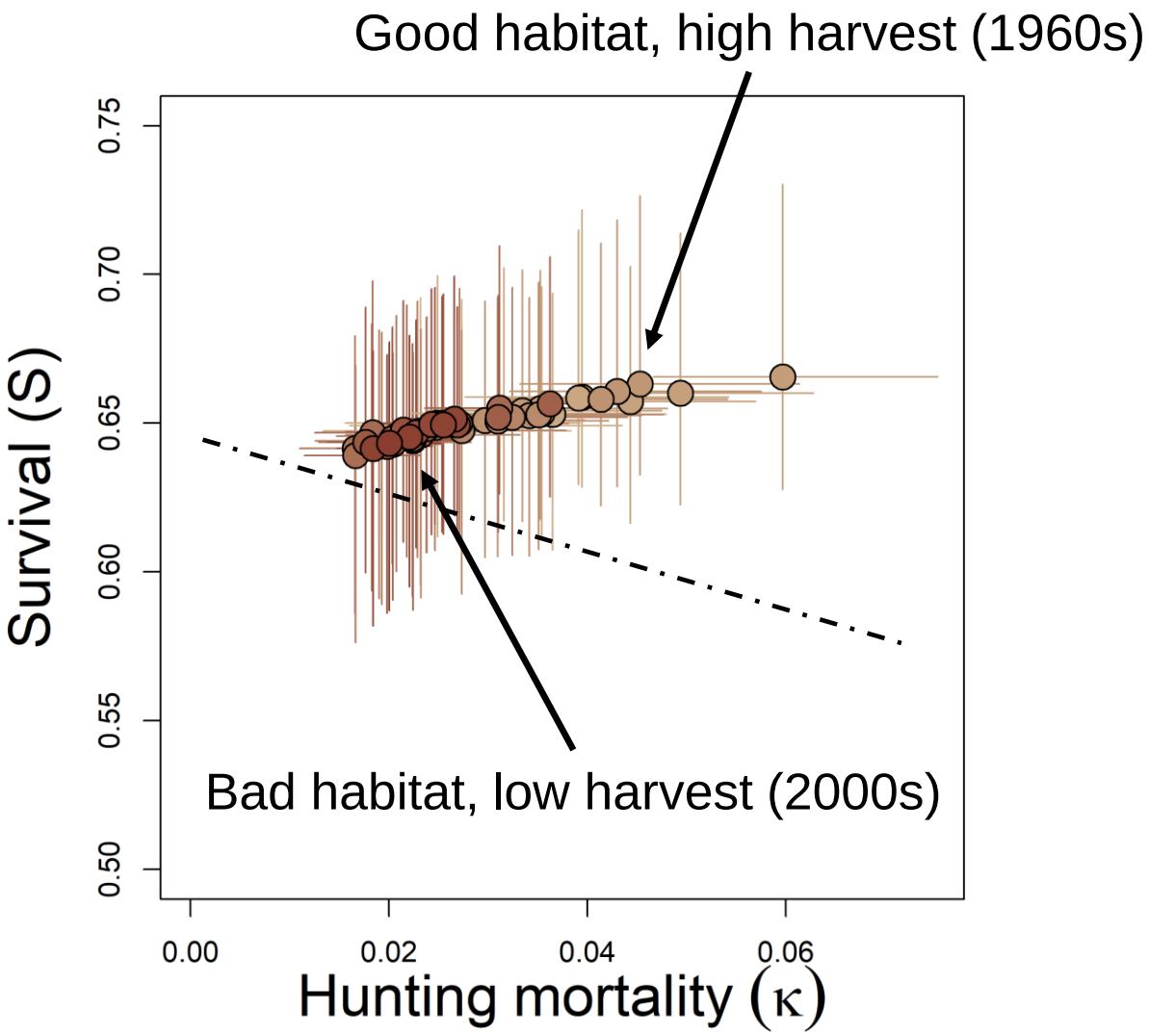
In the past, things were good (hi S and k). Now they aren't.

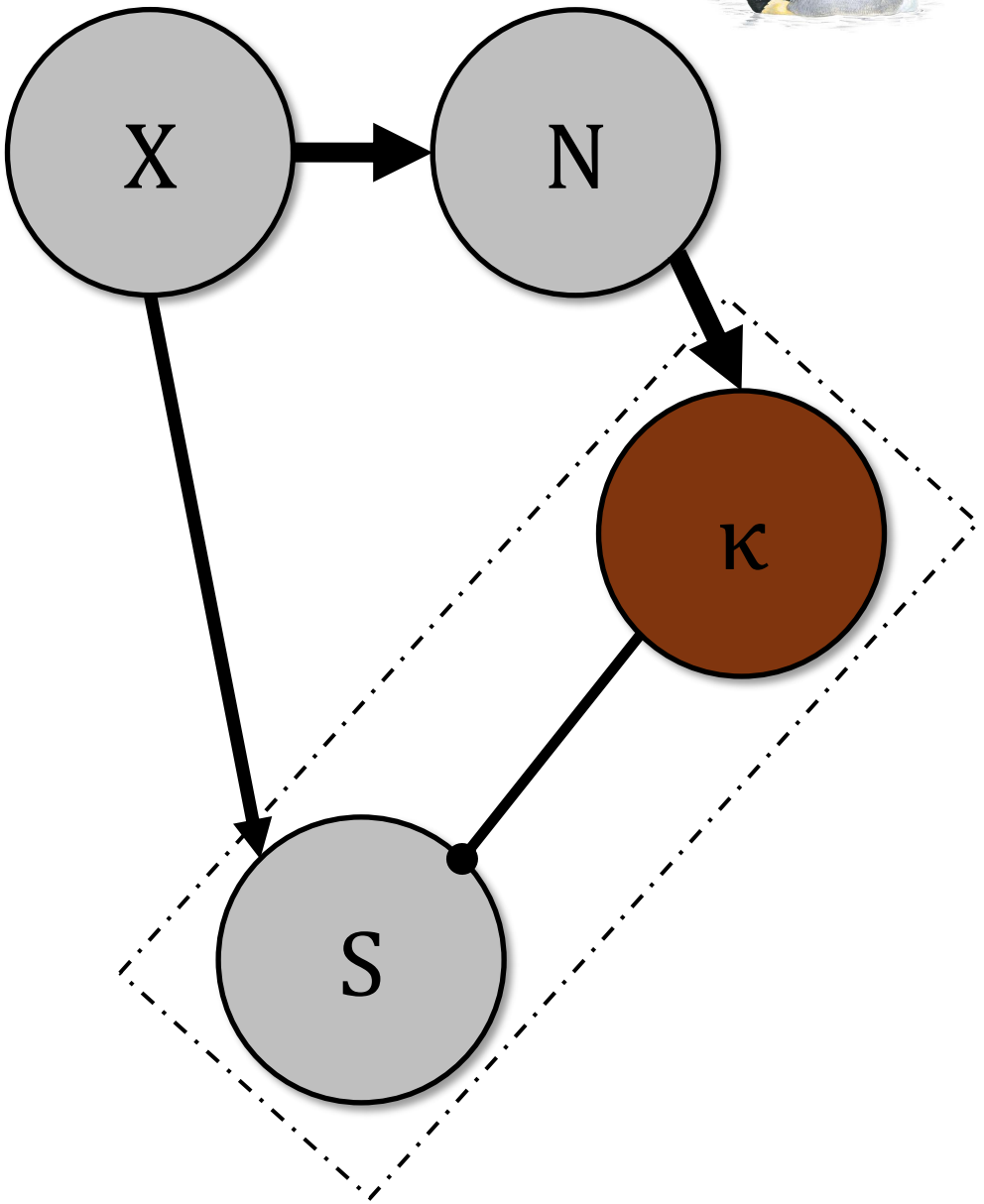
Complicated relationships obscure reality



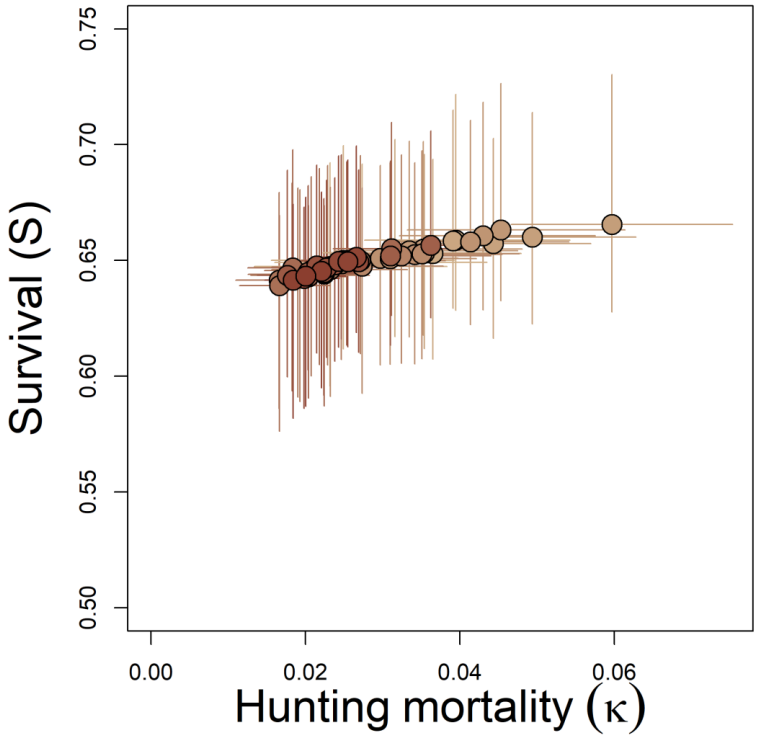


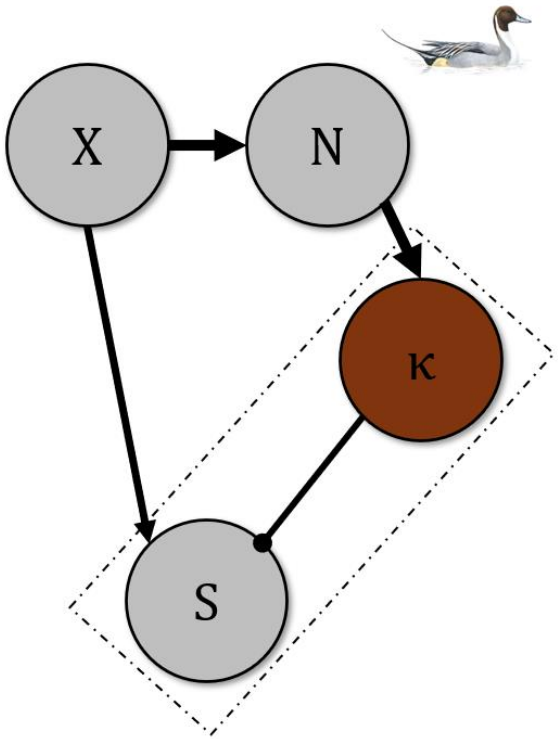
We’re missing the point



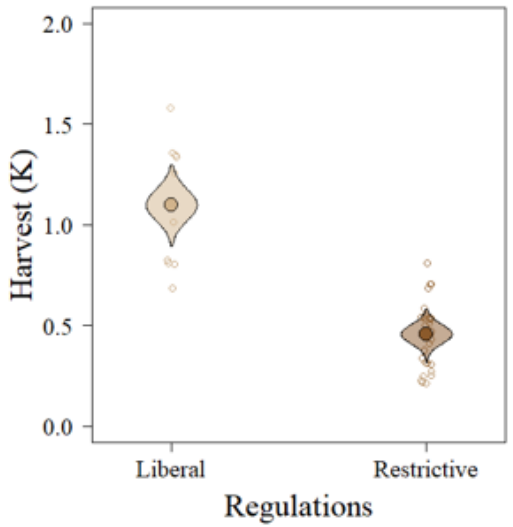


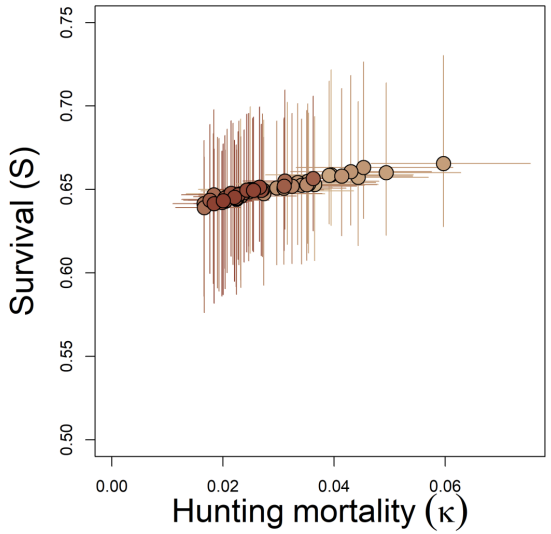
We don’t have to ‘hand-wave,’ we can try to model this stuff

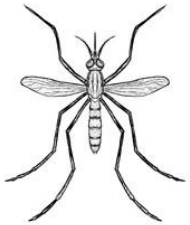


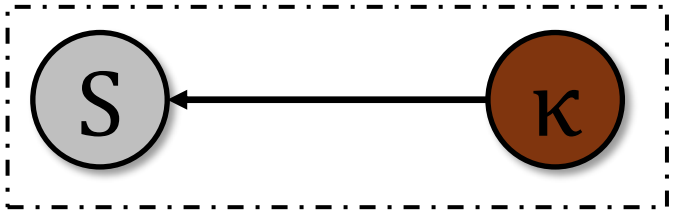


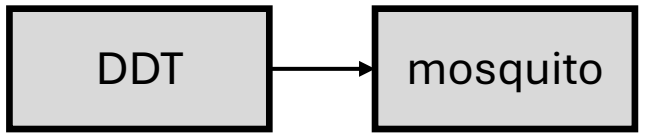
We often make inference and decisions using linear models





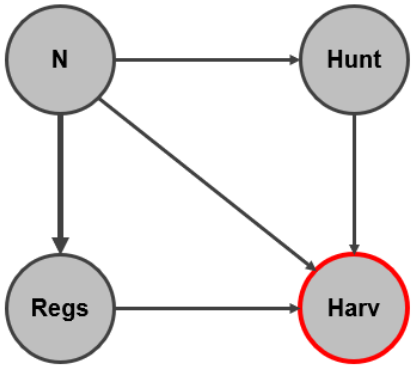


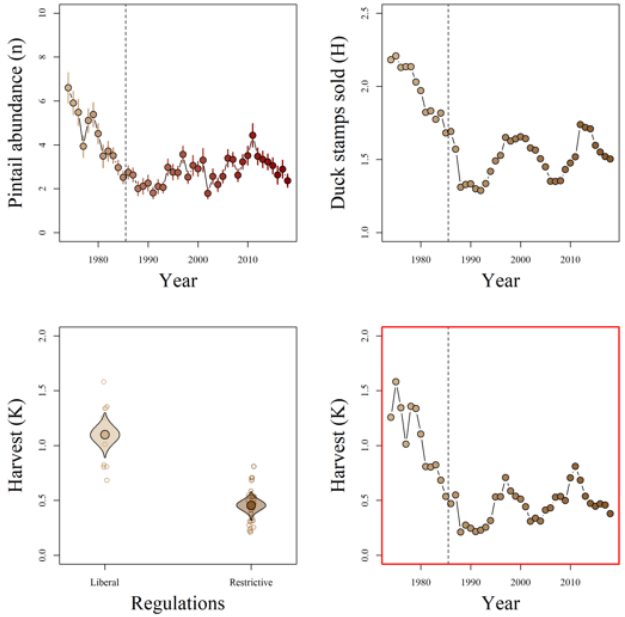


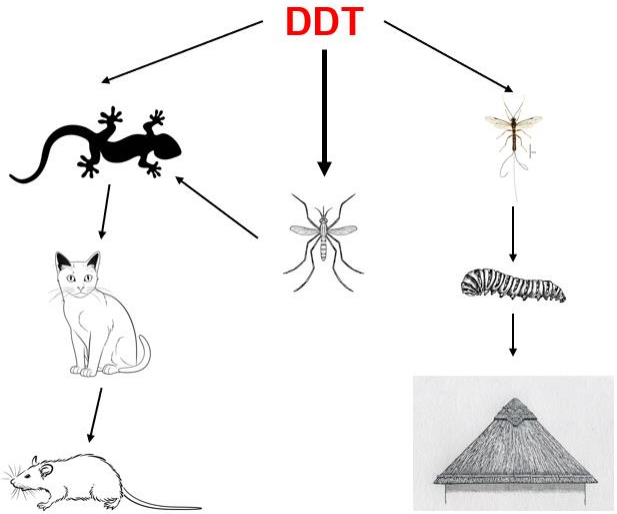


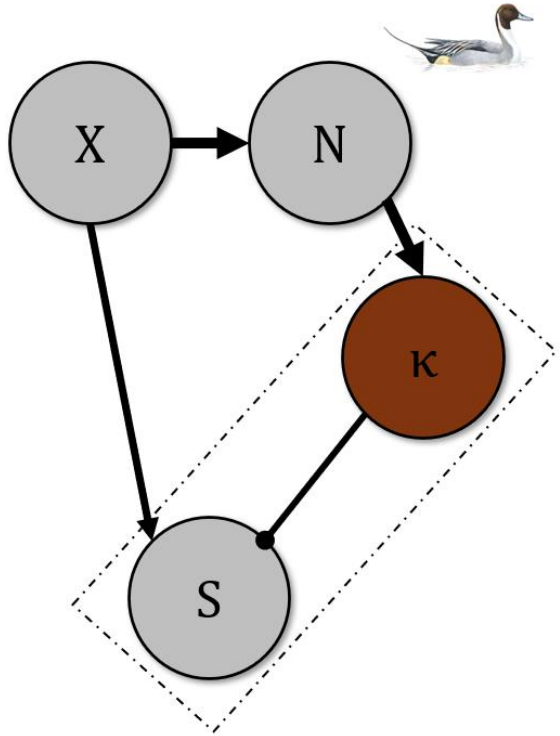
Reality is more complicated, and can kick us in the teeth

SEMs allow us to model <u>in the same way that we think</u>









“If we do this, then 2-3 things will change, and they’ll affect each other”

Before we break…

These models can get pretty complicated pretty quickly…

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RESEARCH ARTICLE

Density-dependence produces spurious relationships among demographic parameters in a harvested species

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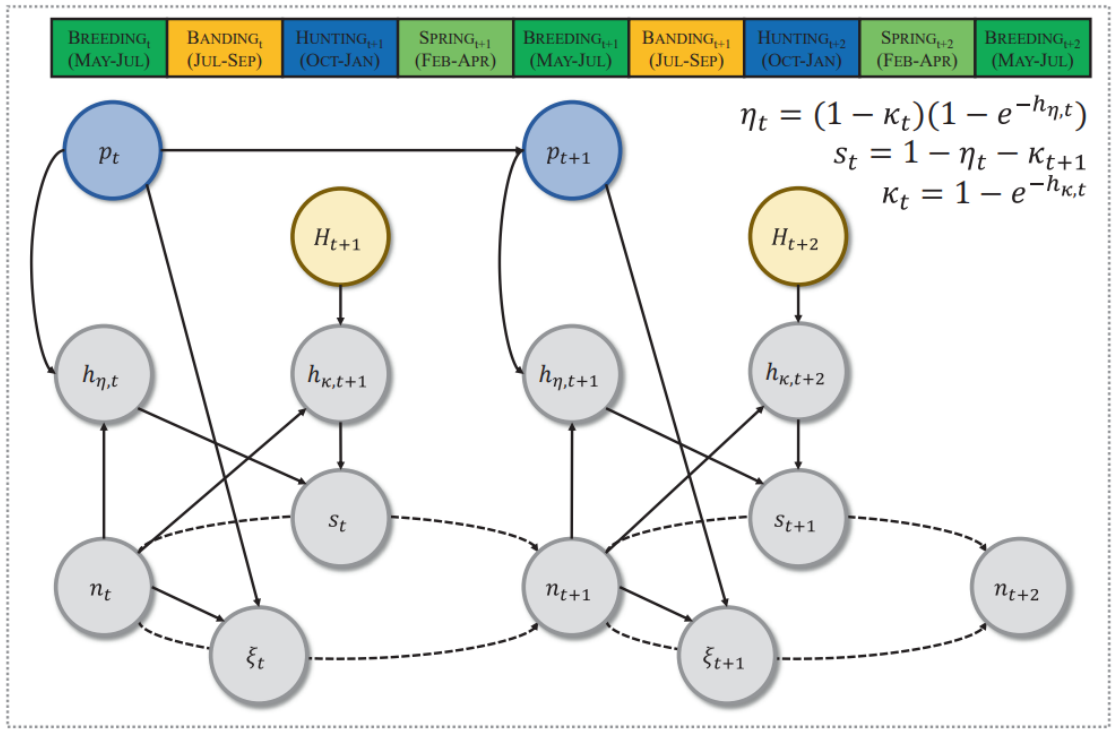
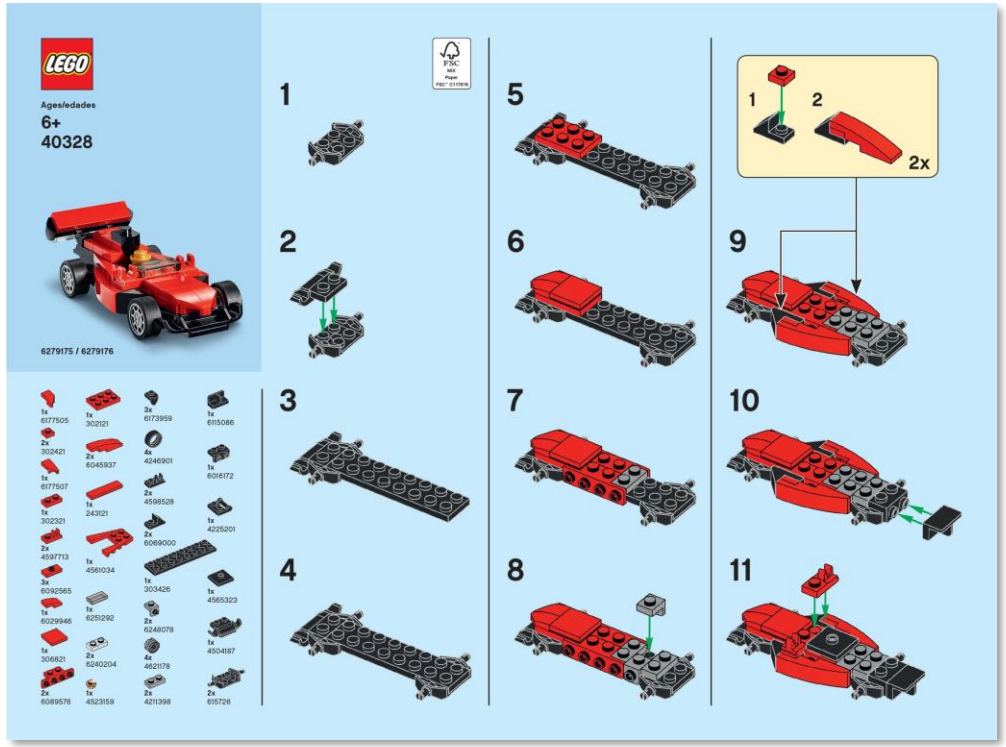


FIGURE 2 A directed acyclic graph demonstrating the relationships among abundance (***n***), ponds (***p***; blue), fecundity (ξ), hunting mortality hazard rate (h_κ), natural mortality hazard rate (h_η), survival (**s**) and the number of duck hunters (***H***; brown) for blue-winged teal breeding in the North American Prairie Pothole Region across the annual cycle (1973–3016). Solid arrows represent estimated directional relationships, and dashed arrows represent processes leading to changes in population abundance.

Lots of stuff gets pretty complicated pretty quickly…



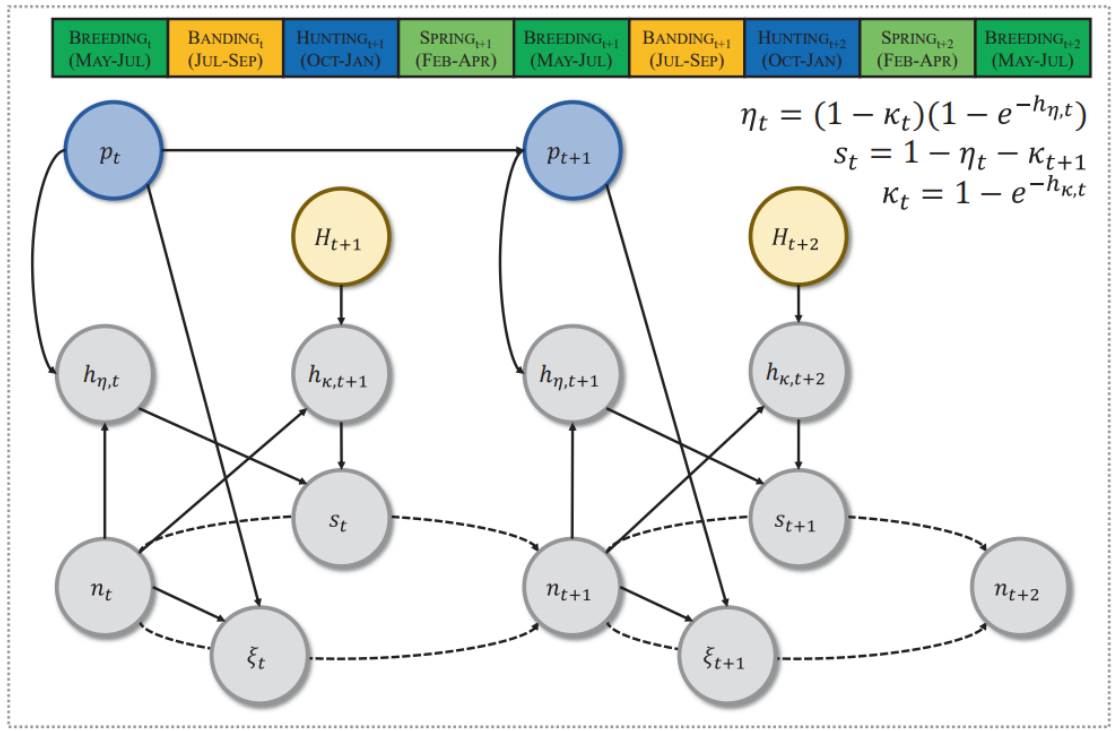


FIGURE 2 A directed acyclic graph demonstrating the relationships among abundance (***n***), ponds (***p***; blue), fecundity (***ξ***), hunting mortality hazard rate ($\boldsymbol{h}_{\kappa}$), natural mortality hazard rate ($\boldsymbol{h}_{\eta}$), survival (**s**) and the number of duck hunters (***H***; brown) for blue-winged teal breeding in the North American Prairie Pothole Region across the annual cycle (1973–3016). Solid arrows represent estimated directional relationships, and dashed arrows represent processes leading to changes in population abundance.

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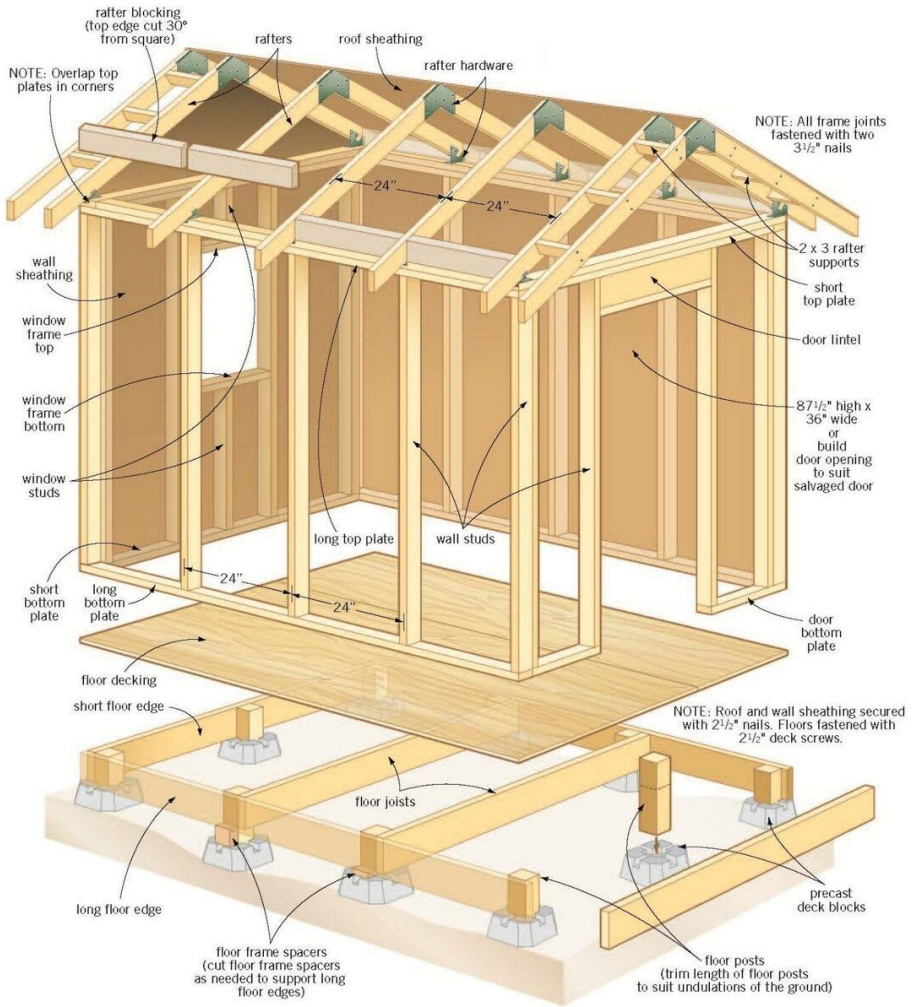


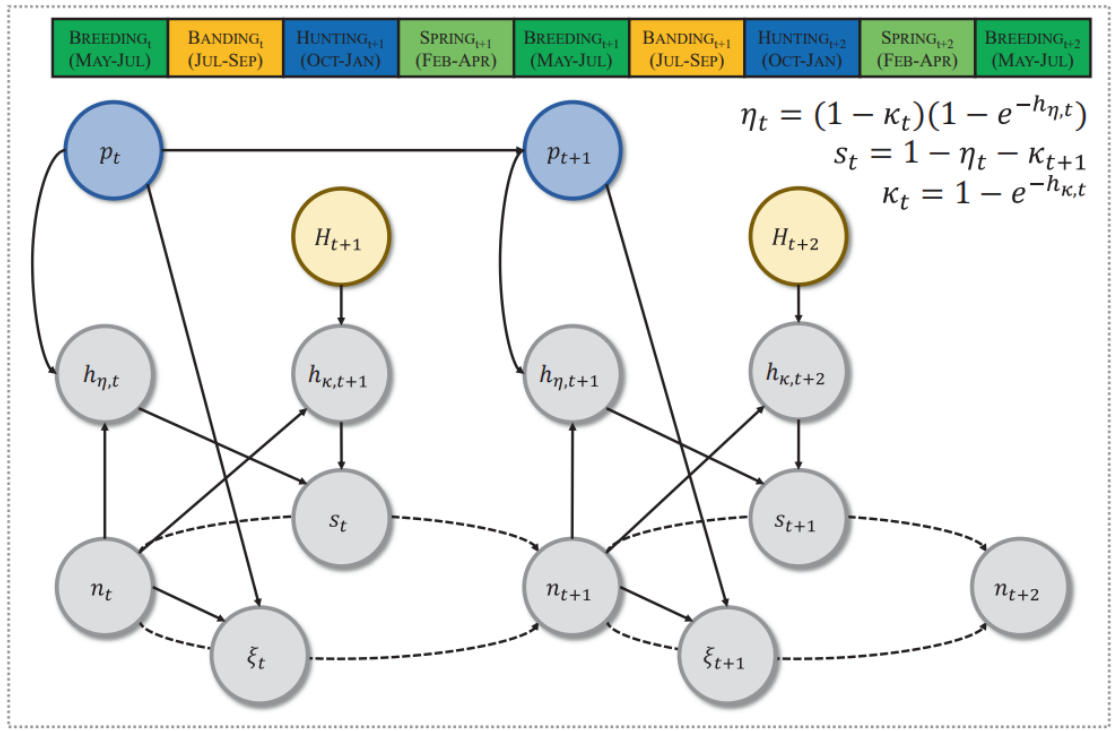
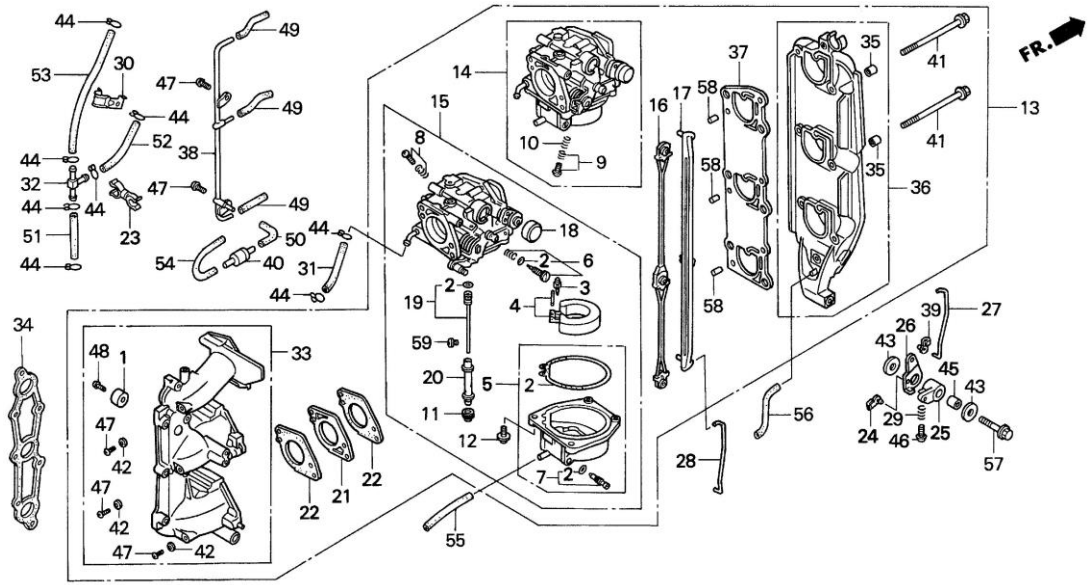
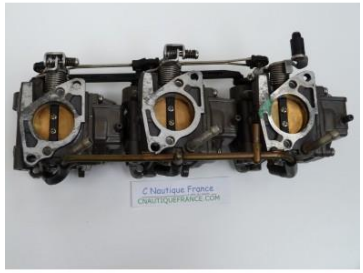


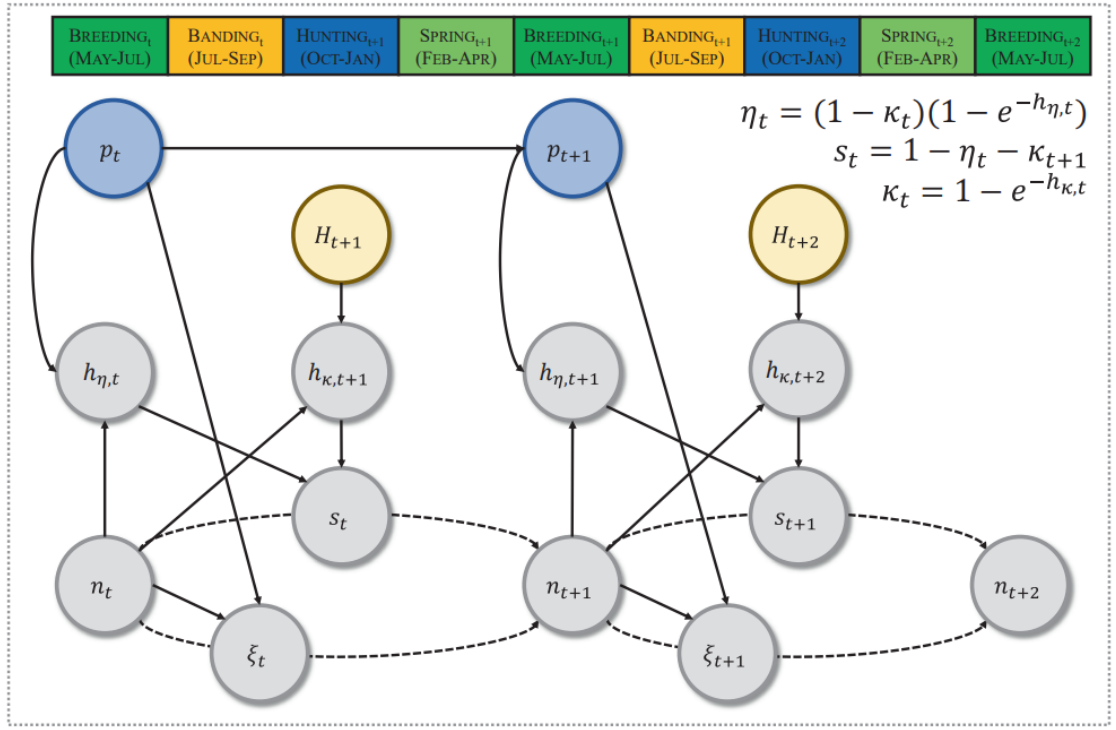
FIGURE 2 A directed acyclic graph demonstrating the relationships among abundance (***n***), ponds (***p***; blue), fecundity (***ξ***), hunting mortality hazard rate (h_κ), natural mortality hazard rate (h_η), survival (**s**) and the number of duck hunters (***H***; brown) for blue-winged teal breeding in the North American Prairie Pothole Region across the annual cycle (1973–3016). Solid arrows represent estimated directional relationships, and dashed arrows represent processes leading to changes in population abundance.

Rough/fine carpentry is at least as hard as statistics

Lots of stuff gets pretty complicated pretty quickly…







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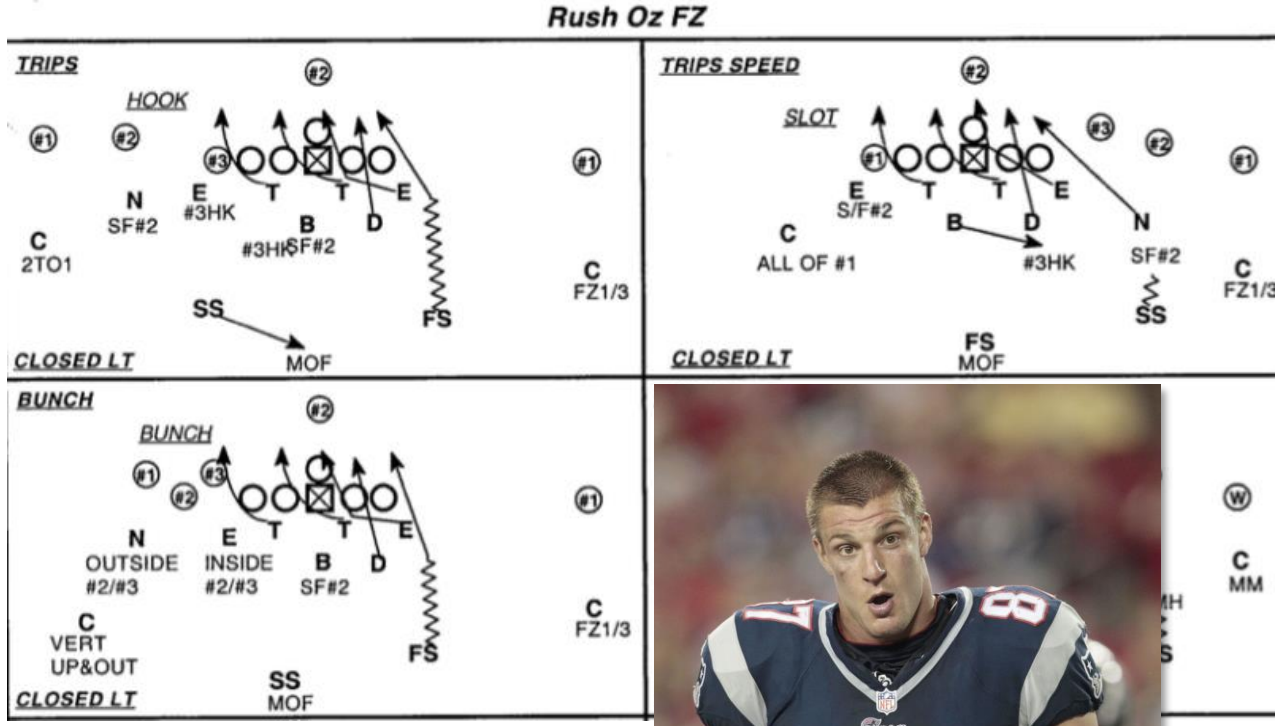
Being a good mechanic is much harder than statistics!

Lots of stuff gets pretty complicated pretty quickly…



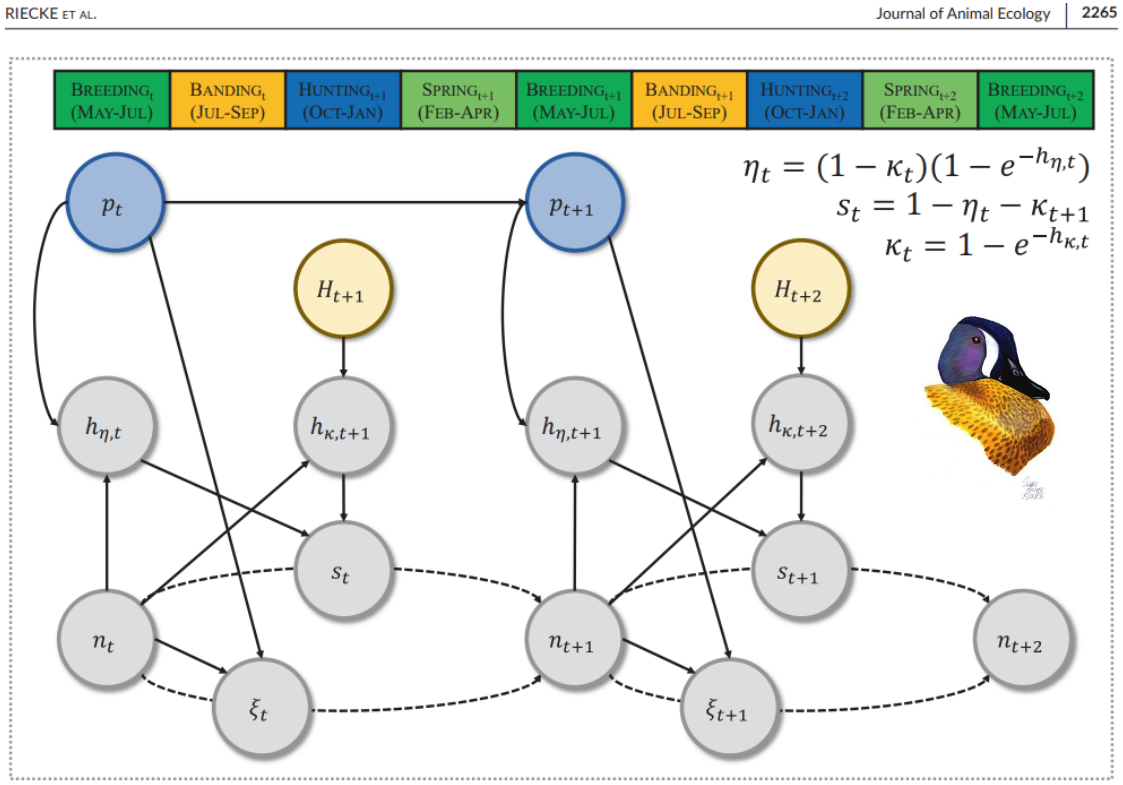


FIGURE 2 A directed acyclic graph demonstrating the relationships among abundance (***n***), ponds (***p***; blue), fecundity (ξ), hunting mortality hazard rate (h_κ), natural mortality hazard rate (h_η), survival (**s**) and the number of duck hunters (***H***; brown) for blue-winged teal breeding in the North American Prairie Pothole Region across the annual cycle (1973–3016). Solid arrows represent estimated directional relationships, and dashed arrows represent processes leading to changes in population abundance.

Heck sports might be harder! All these things just take <u>time</u> to learn!

Next up, path analysis…