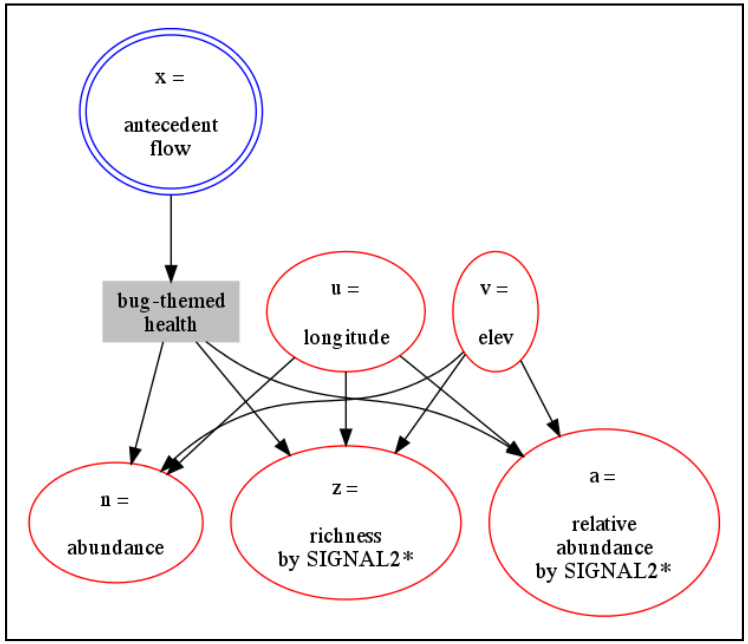
LHFI: statistical model-based inference for stream health

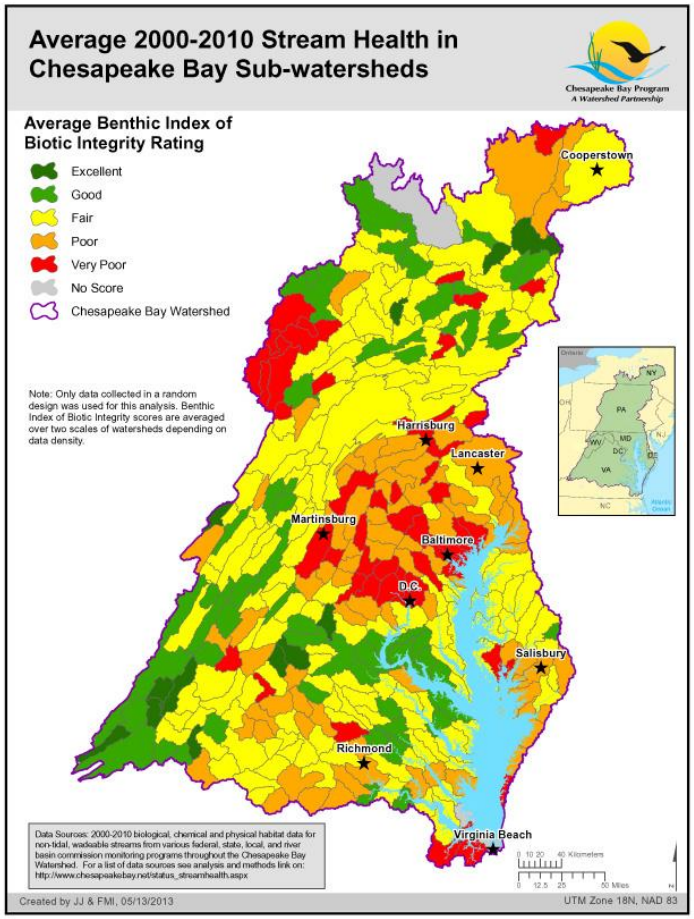


Grace S Chiu[1,2,3,4,5]

[1] VIMS www.vims.edu/people/chiu_gs
[2] VCU, Department of Statistical Sciences & Operations Research
[3] U of Washington, Department of Statistics
[4] U of Waterloo, Department of Statistics and Actuarial Science
[5] ANU Climate Change Institute

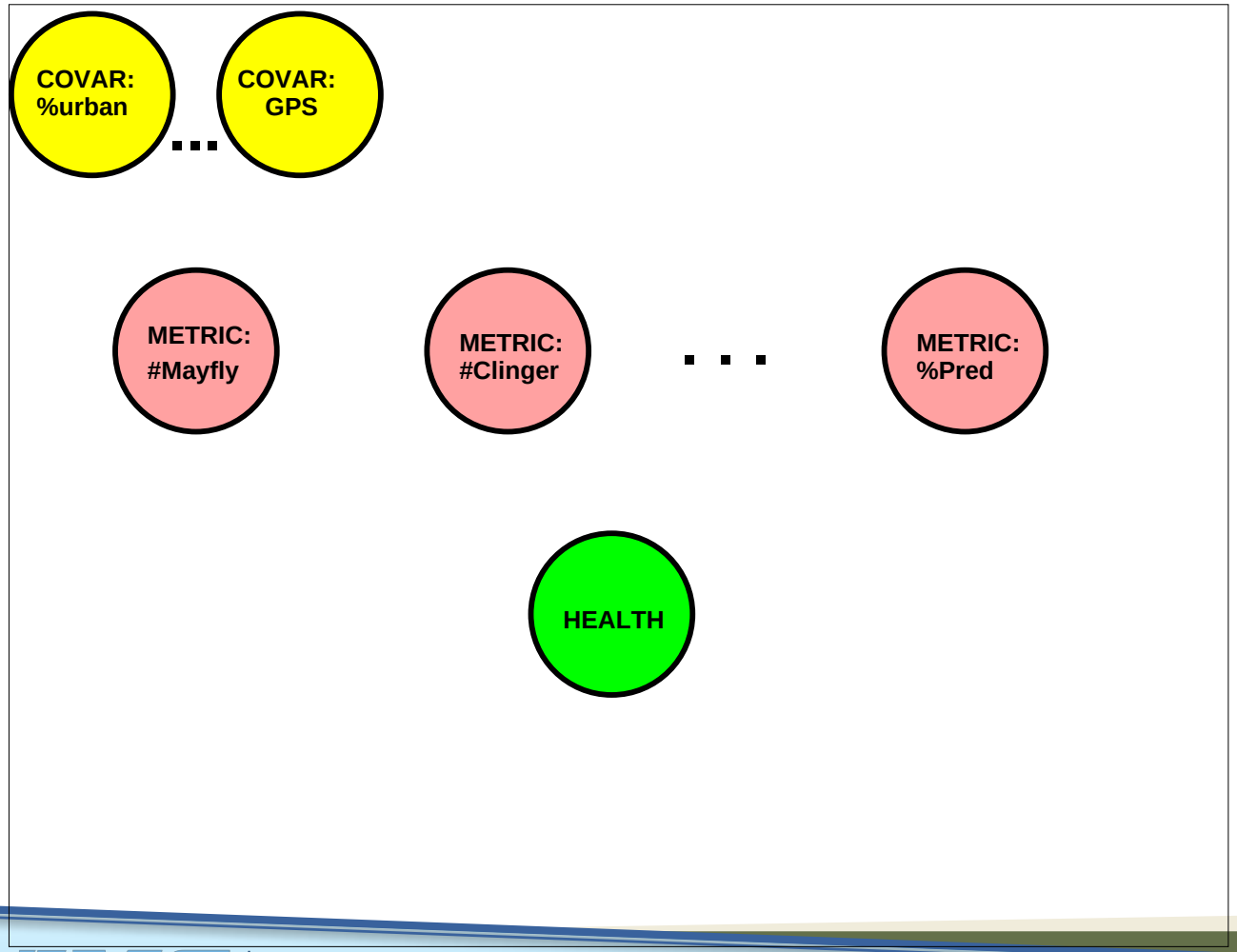
1. Conventional vs LHFI

Chessie BIBI & other conventional report-card approaches



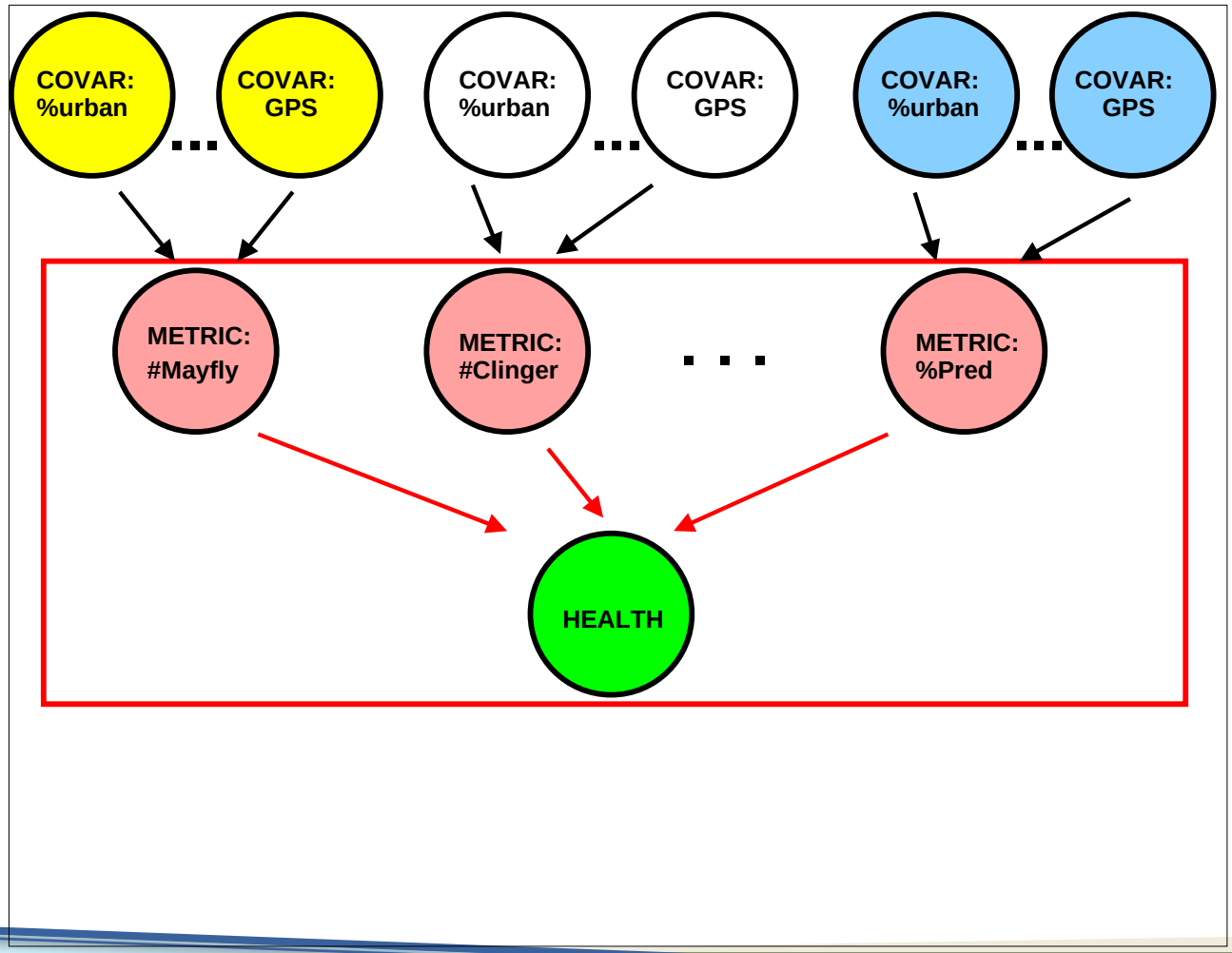
Source: chesapeakenetwork.org/resources/chessie-bibi-overview

Chessie BIBI & other conventional report-card approaches



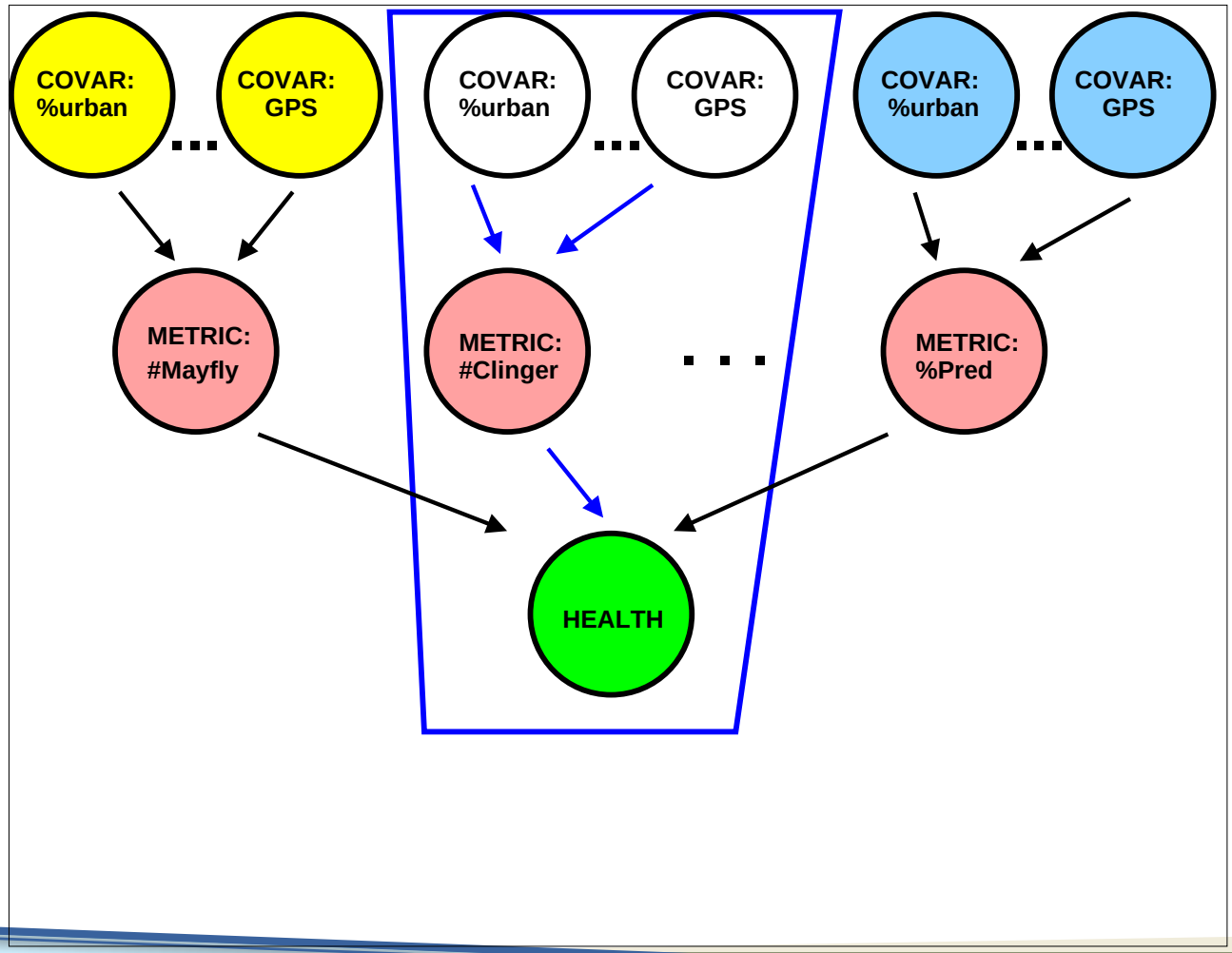
Chessie BIBI & other conventional report-card approaches

BIBI (multimetric index)



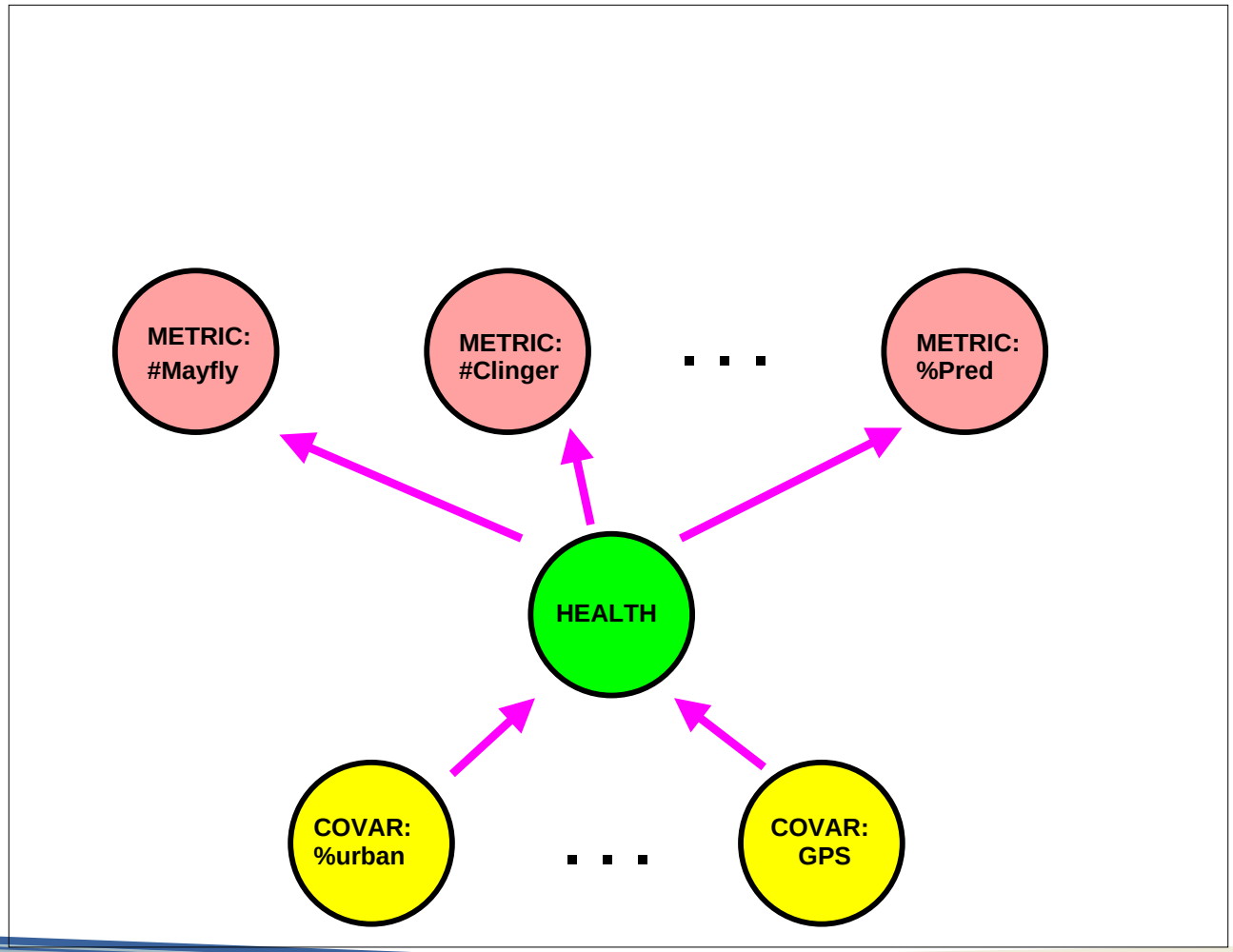
Chessie BIBI & other conventional report-card approaches

RivPACS (O/E index)



Model-based Latent Health Factor Index

LHFI



Model-based Latent Health Factor Index

LHFI modeling is a framework

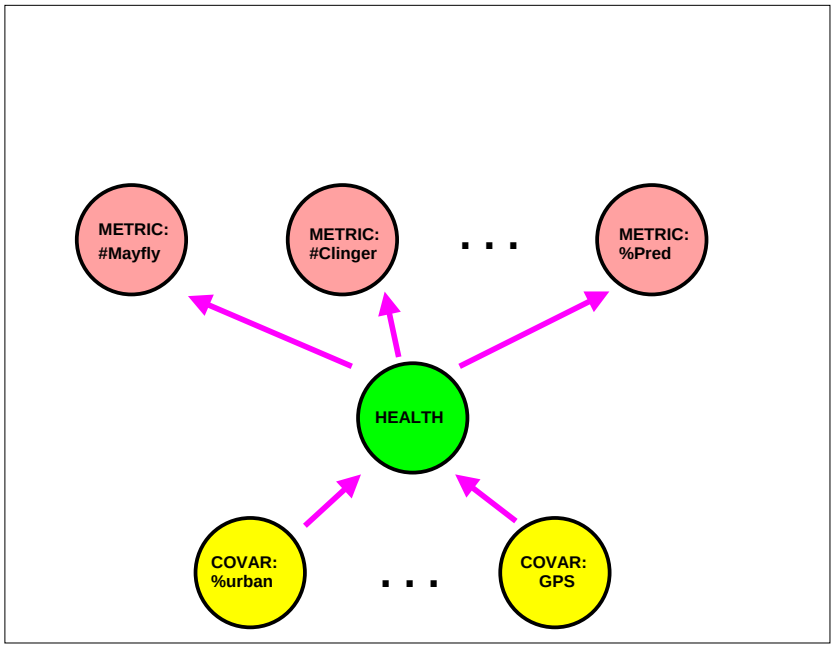
- different ecosystems may require different model structures

Model-based Latent Health Factor Index

LHFI modeling is a framework

- different ecosystems may require different model structures
  - see `tinyurl.com/chiu-lhfi`

Model-based Latent Health Factor Index



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Research Article

Latent health factor index: a statistical modeling approach for ecological health assessment

Grace S. Chiu[1,*], Peter Guttorp[2], Anton H. Westveld[3], Shahedul A. Khan[4], Jun Liang[5]

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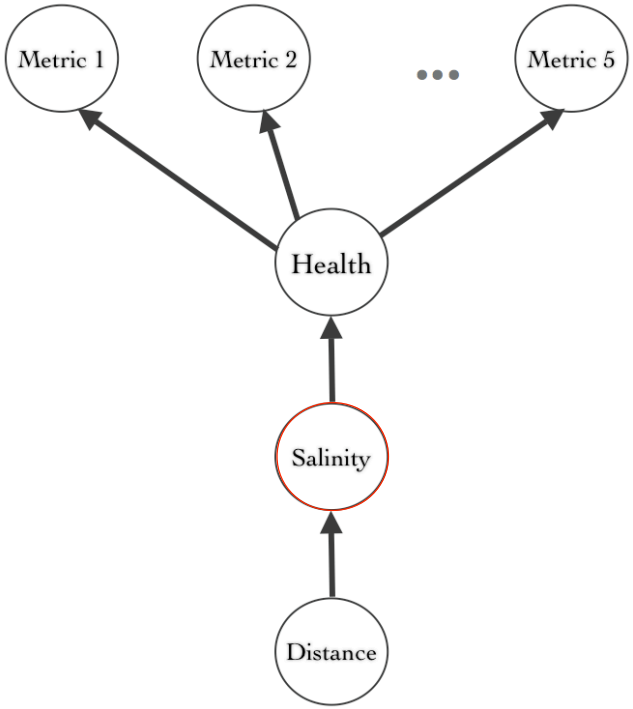
Model-based Latent Health Factor Index



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Model-Based Assessment of Estuary Ecosystem Health Using the Latent Health Factor Index, with Application to the Richibucto Estuary

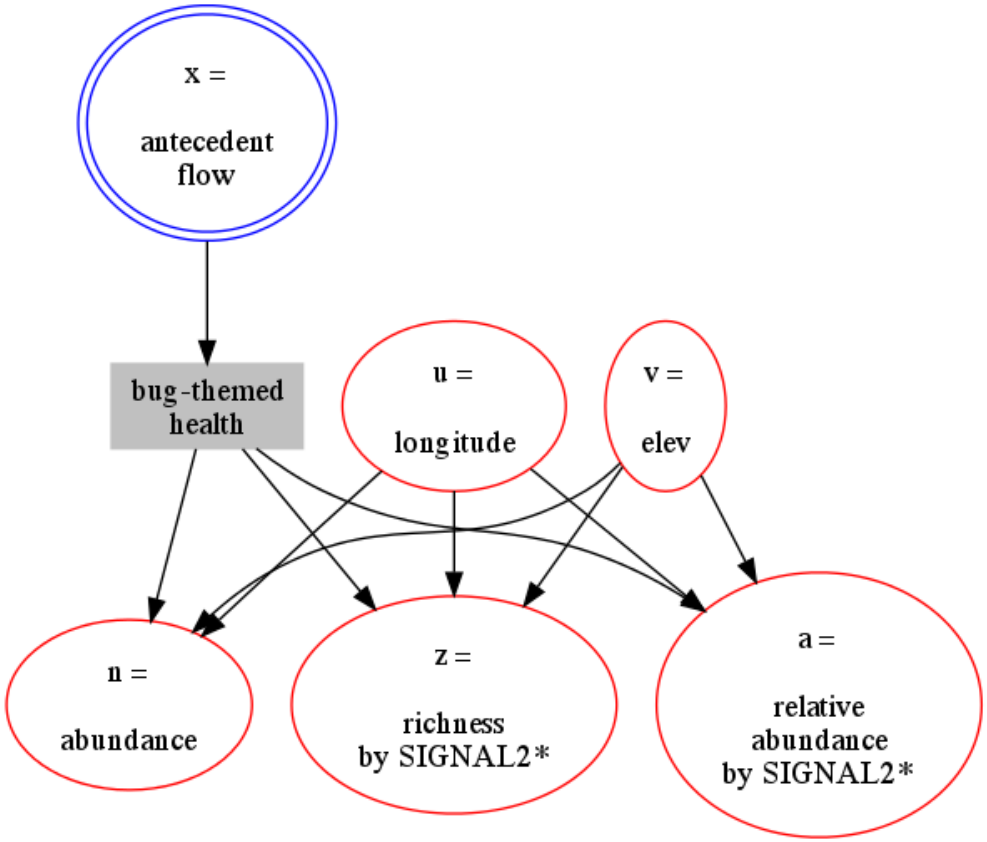
Grace S. Chiu[1]*, Margaret A. Wu[2], Lin Lu[3]

1 CSIRO Mathematics, Informatics and Statistics, Commonwealth Scientific and Industrial Research Organisation (CSIRO), Canberra, Australian Capital Territory, Australia, **2** Business Methods Survey Division, Statistics Canada, Ottawa, Ontario, Canada, **3** McGregor GeoScience, Bedford, Nova Scotia, Canada

Abstract

The ability to quantitatively assess ecological health is of great interest to those tasked with monitoring and conserving ecosystems. For decades, biomonitoring research and policies have relied on multimetric health indices of various forms. Although indices are numbers, many are constructed based on qualitative procedures, thus limiting the quantitative rigor of the practical interpretations of such indices. The statistical modeling approach to construct the latent health factor index (LHFI) was recently developed. With ecological data that otherwise are used to construct conventional multimetric indices,

Model-based Latent Health Factor Index



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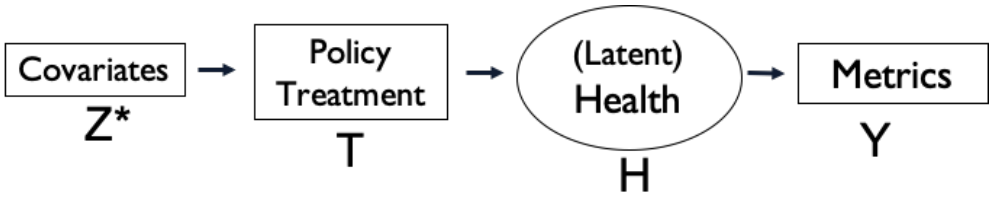
Redefining the concept of ecological health: assessment and prediction of health as model parameters at multiple spatial scales across a continental-scale river basin

September 2014

Conference: 99th Ecological Society of America Annual Meeting 2014

Grace S. Chiu · Stuart E Bunn · Fran Sheldon

Model-based Latent Health Factor Index



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[Submitted on 24 Sep 2020]

Latent Causal Socioeconomic Health Index

F. Swen Kuh, Grace S. Chiu, Anton H. Westveld

This research develops a model-based LAtent Causal Socioeconomic Health (LACSH) index at the national level. We build upon the latent health factor index (LHFI) approach that has been used to assess the unobservable ecological/ecosystem health. This framework integratively models the relationship between metrics, the latent health, and the covariates that drive the notion of health. In this paper, the LHFI structure is integrated with spatial modeling and statistical causal modeling, so as to evaluate the impact of a continuous policy variable (mandatory maternity leave days and government's expenditure on healthcare, respectively) on a nation's socioeconomic health, while formally accounting for spatial dependency among the nations. A novel visualization technique for evaluating covariate balance is also introduced for

Model-based Latent Health Factor Index

A *SSESSMENT: appropriate interpretation of a suite of biotic metrics (e.g., species richness/abundance)*

P *REDICTION: modeling biotic-to-biotic and/or abiotic-to-biotic relations*

Model-based Latent Health Factor Index

`A` *SSESSMENT: appropriate interpretation of a suite of biotic metrics (e.g., species richness/abundance)*

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Conventional approaches regard `A&P` as SEPARATE procedures

Model-based Latent Health Factor Index

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Conventional approaches regard `A&P` as SEPARATE procedures

My biomonitoring research:

To facilitate evidence-based policy-making

$\Longrightarrow$ rigor

$\Longrightarrow$ development of single hierarchical model

2. Examples of LHFI work

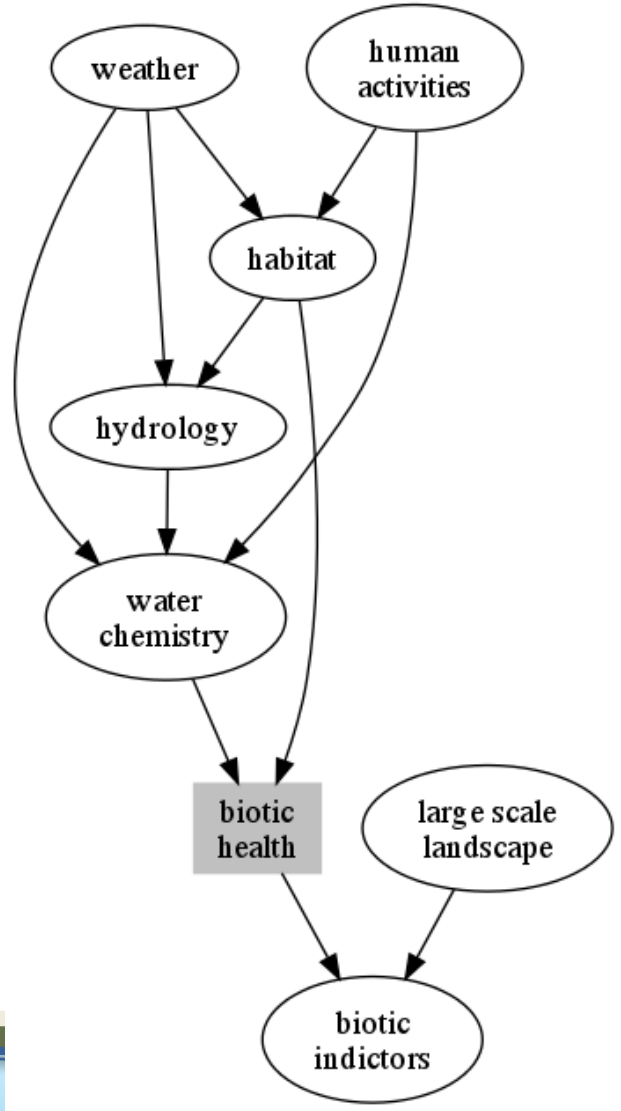
While at CSIRO: Murray-Darling Basin

I was developing model for

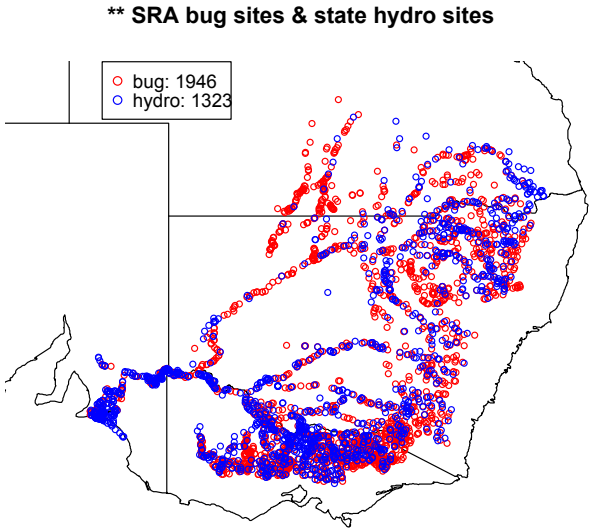
- Ovals are data
- HEALTH is model parameter
  - to be estimated
- Model handles spatial misalignment over multiple spatial and ecological scales
- Model-based interpolation of biotic response when samples are missing

  $\Longrightarrow$ cost effective,

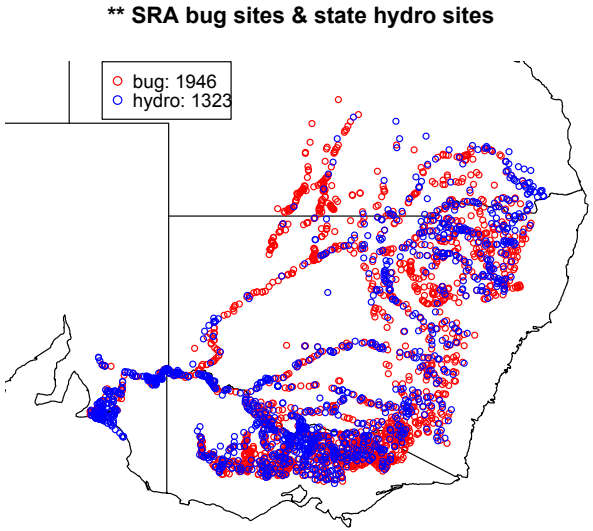
  rigor in uncertainty propagation

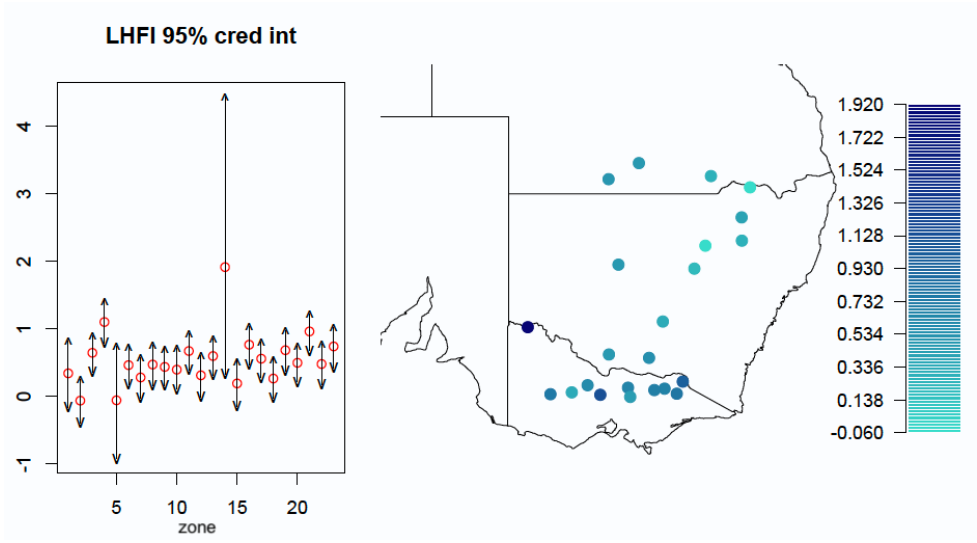


While at CSIRO: Murray-Darling Basin



While at CSIRO: Murray-Darling Basin





While at CSIRO: Murray-Darling Basin

Key model statements:

$$H_{ijt} = \phi_i + \beta_i x_{ijt} + \varepsilon_{ijt} \qquad H_i := \phi_i + \beta_i \bar{x}_{i..}$$

x: antecedent log(hydro discharge) $\qquad \{\phi_i\} \sim$ mean-0 CAR

$$\beta_i \sim N(\beta, \omega_b^2) \qquad \varepsilon_{ijt} \sim N(0, \gamma_i \sigma_e^2)$$

$$y_{rijtk} = \alpha_{0r} + \alpha_{1r} u_{ij} + \alpha_{2r} v_{ij} + \alpha_{3r} H_{ijt} + \eta_{rijtk}$$

$$\begin{bmatrix} \eta_{1ijtk} \\ \eta_{2ijtk} \\ \eta_{3ijtk} \end{bmatrix} \sim \text{MVN}(\mathbf{0}, \mathbf{\Sigma}_i)$$

$r \in \{1{=}\text{log-abund.}, 2{=}\text{weighted rich.}, 3{=}\text{weighted rel. abund.}\}$

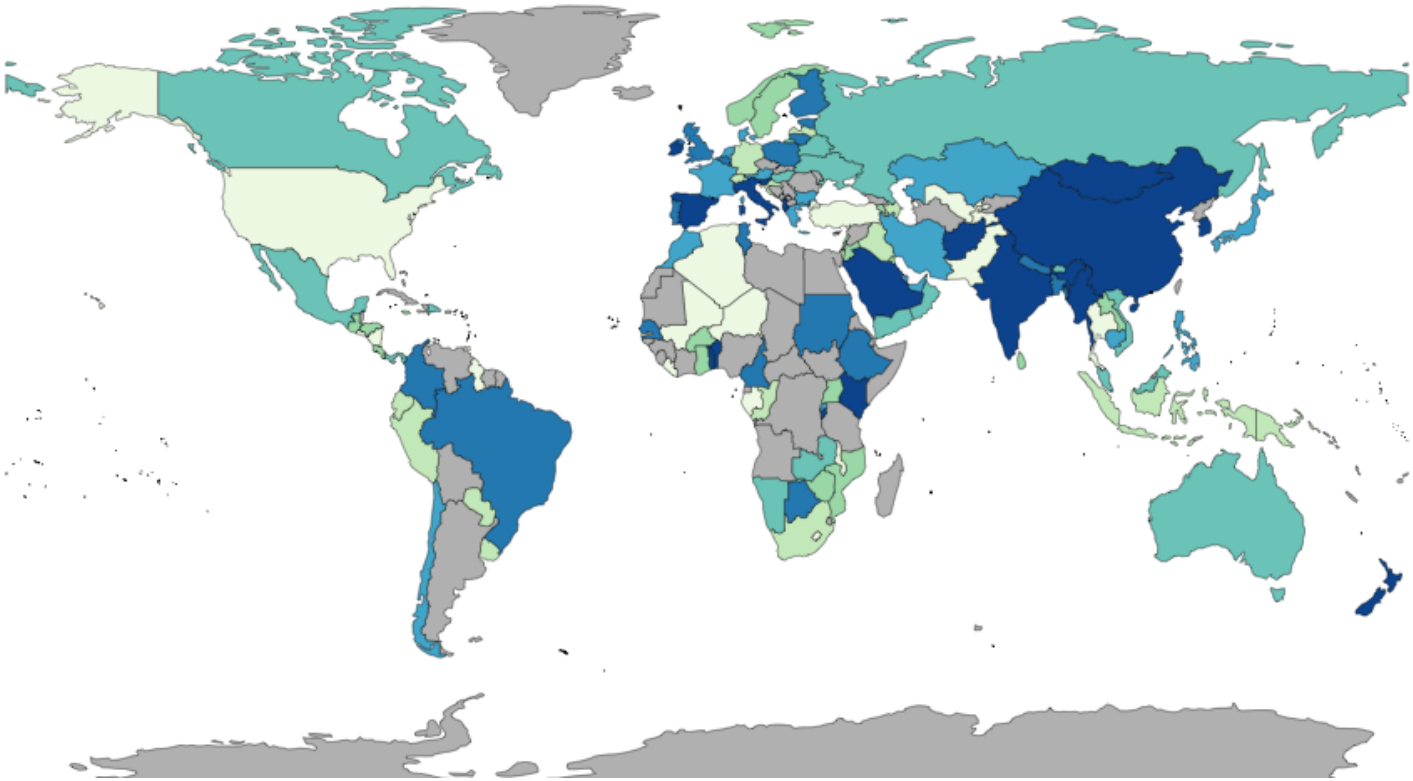
u, v: longitude, log(elevation)

While at ANU/VIMS: LACSH

Latent **C**ausal **S**ocio-economic **H**ealth

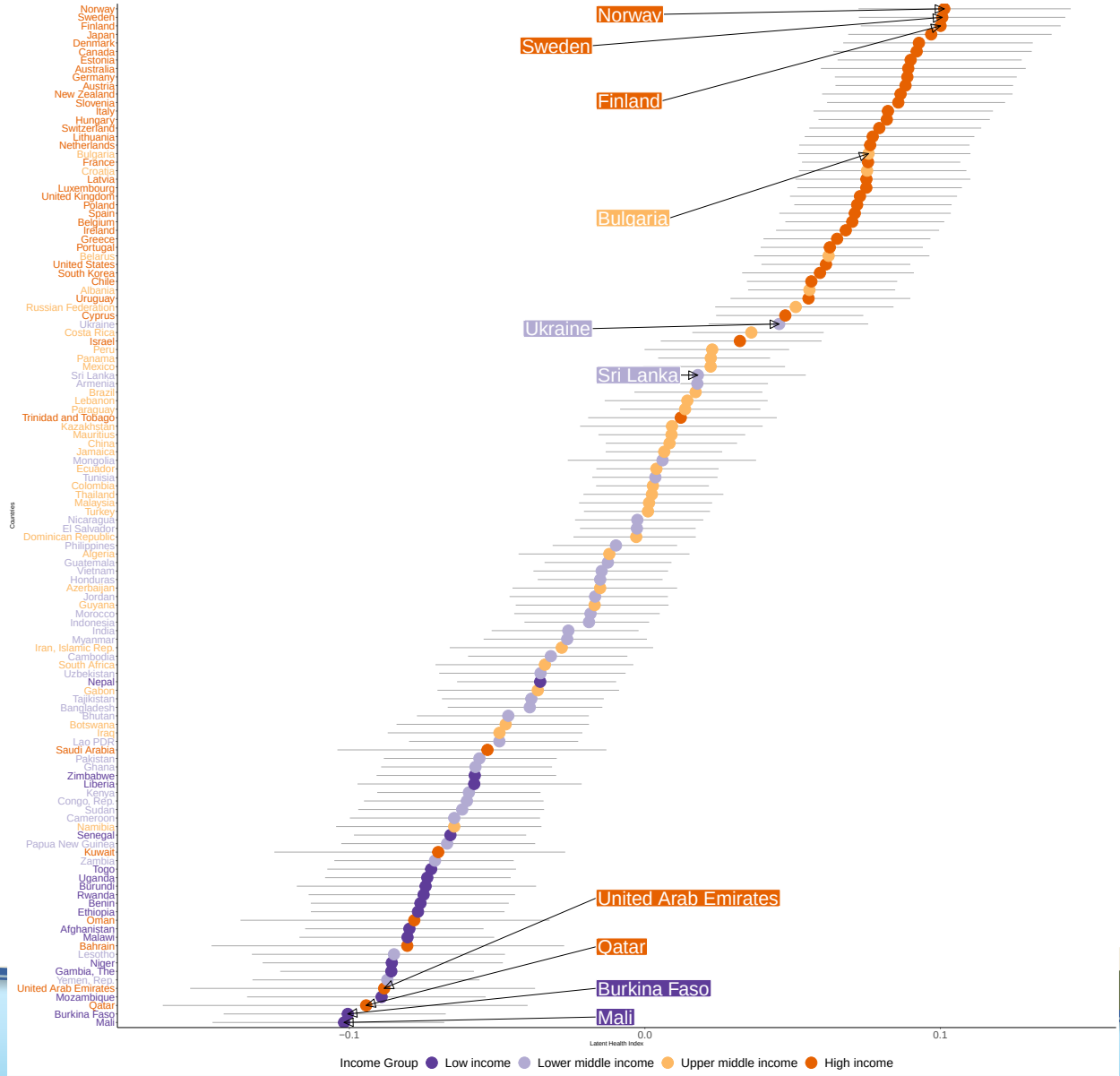
While at ANU/VIMS: LACSH

Latent **C**ausal **S**ocio-economic **H**ealth

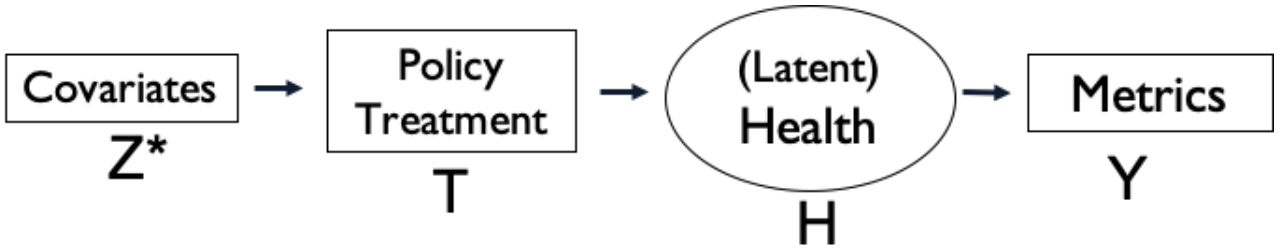


While at ANU/VIMS: LACSH

Causal variable:
Mandatory
maternity leave days



While at ANU/VIMS: LACSH



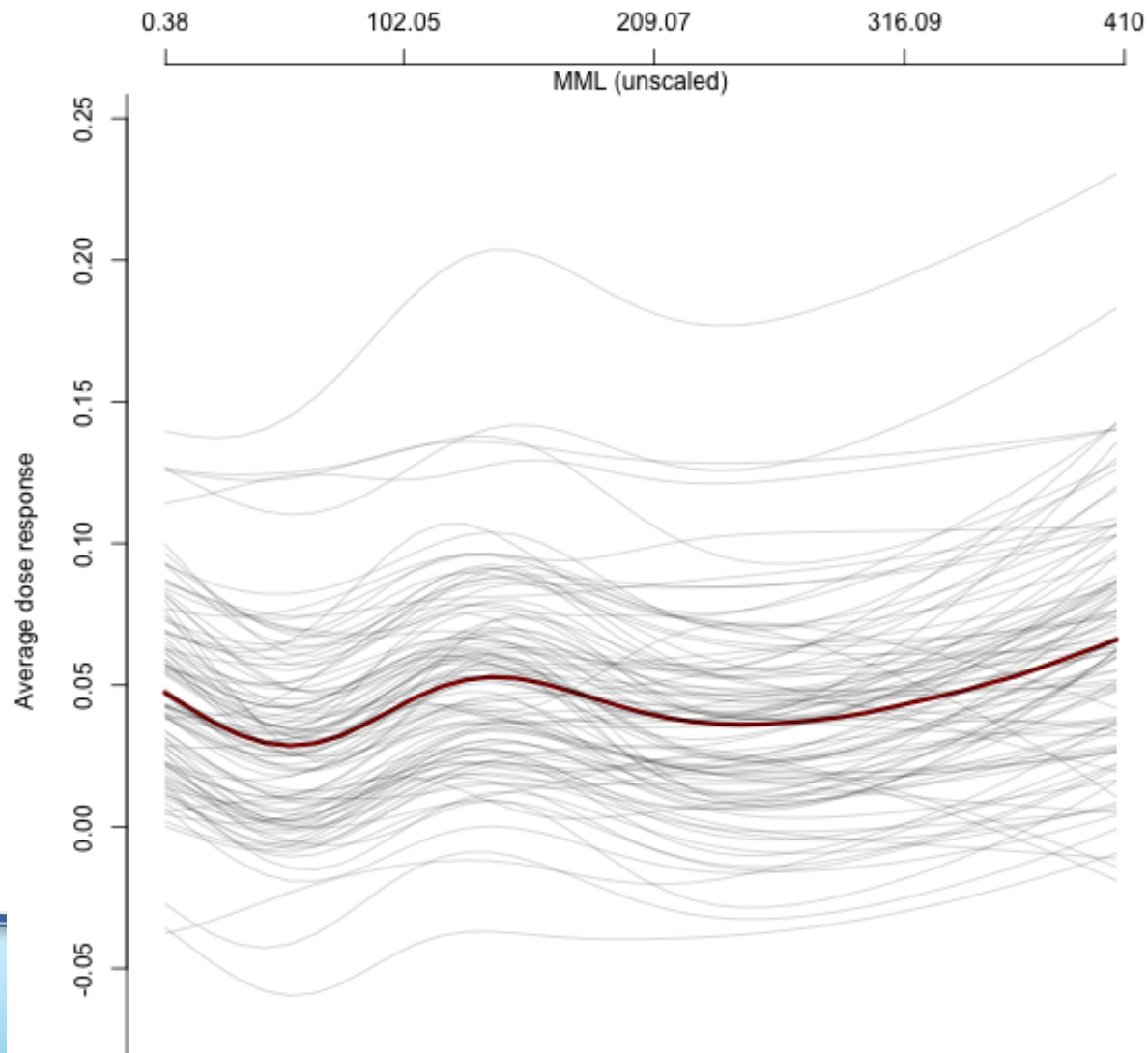
$$
\begin{aligned}
\boldsymbol{y}_i|\boldsymbol{a}, H_i, \Sigma_Y &\overset{ind.}{\sim} \text{MVN}(\boldsymbol{a}H_i, \Sigma_Y) \\
\boldsymbol{H}|\boldsymbol{\beta}, \boldsymbol{T}, \boldsymbol{R}, \Sigma_H &\sim \text{TMVN}(\boldsymbol{\mu}, \Sigma_H)\mathbb{1}\{H_{anc} < 0\} \\
T_i|\boldsymbol{Z}_i^*, \boldsymbol{\gamma}, \sigma_T^2 &\sim \text{N}(\boldsymbol{Z}_i^*\boldsymbol{\gamma}, \sigma_T^2) \\
\text{where} \qquad [\boldsymbol{\mu}]_i &= \beta_0 + \beta_1 T_i + \beta_2 T_i^2 + \beta_3 R_i + \beta_4 R_i^2 + \beta_5 T_i R_i \\
R_i = r(T_i, \boldsymbol{\gamma}, \boldsymbol{Z}_i^*, \sigma_T^2) &= \frac{1}{\sqrt{2\pi}\sigma_T} \exp\left(-\frac{1}{2\sigma_T^2}(T_i - \boldsymbol{Z}_i^*\boldsymbol{\gamma})^2\right) \\
\Sigma_H &= \sigma_H^2 \boldsymbol{\Omega}(d, \phi) \\
\boldsymbol{\Omega}(d, \phi) &= \begin{bmatrix} 1 & \rho_{12} & \cdots & \rho_{1n} \\ \rho_{21} & 1 & \ddots & \vdots \\ \vdots & \ddots & \ddots & \rho_{n-1,n} \\ \rho_{n1} & \cdots & \rho_{n,n-1} & 1 \end{bmatrix} \\
\rho_{nm} &= exp(-d_{nm}/\phi) = \rho_{mn}
\end{aligned}
$$

⟵ causal framework: generalized propensity score

While at ANU/VIMS: LACSH

Causal relationship:

Health vs. Maternity Leave Days



LHFI/LACSH in a nutshell

LHFI/LACSH in a nutshell

- Single hierarchical model / one-stop shop
  - unifies various aspects of health
  - rigor in uncertainty propagation
- Health is model parameter
  - formal uncertainty quantification
- No big deal when biotic data are missing
- Rigorous assessment of policy (causal) effects on health

References

- `tinyurl.com/chiu-lhfi`
- Search for `Grace S Chiu` on Research Gate or Google Scholar