Challenges in understanding impacts of anthropogenic pressures on ecosystem recovery

Laura Uusitalo, PhD (fisheries science), PhD (computer science)

VELMU conference, 14 March 2023 in Helsinki, Finland

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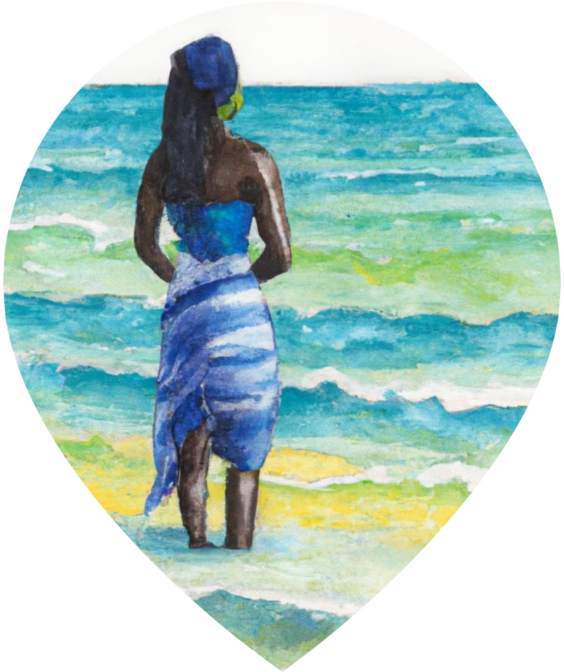
Challenge 1:

Understanding



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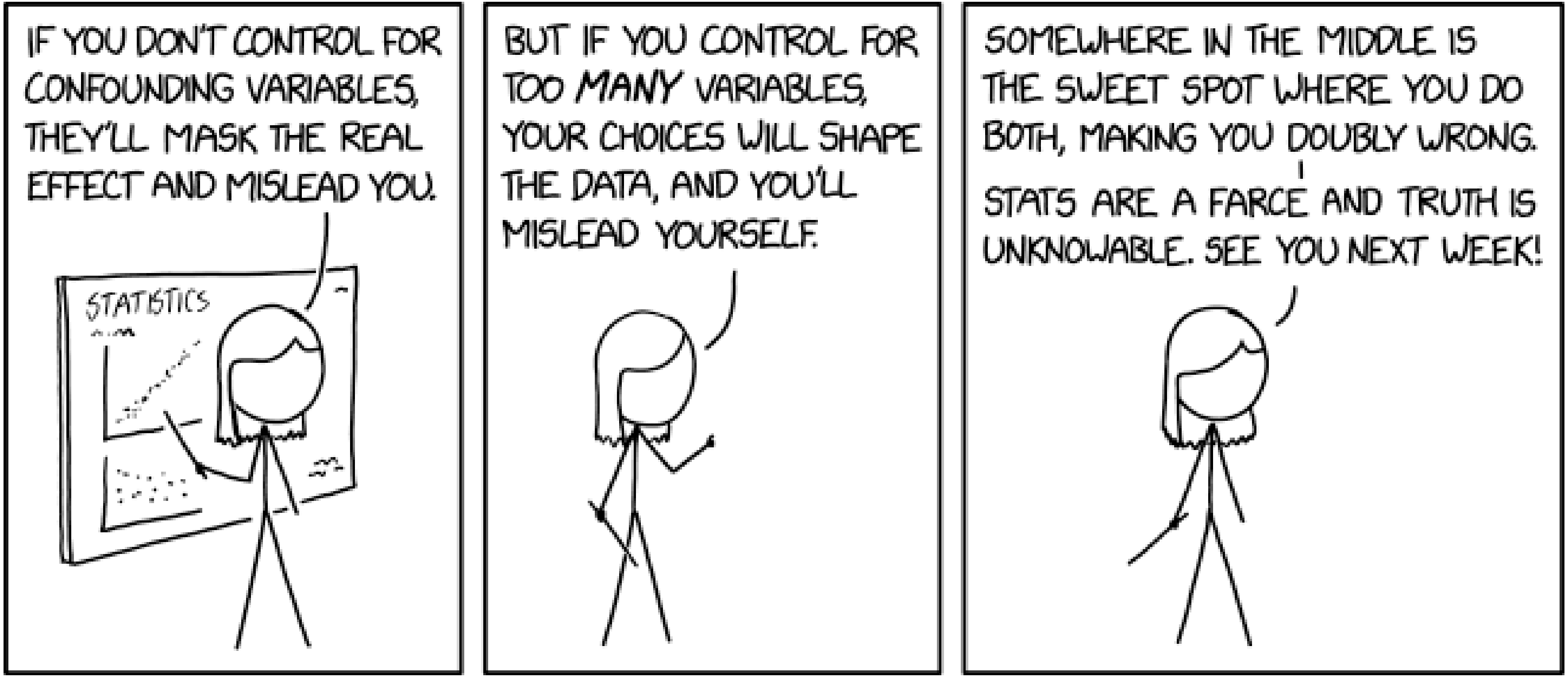
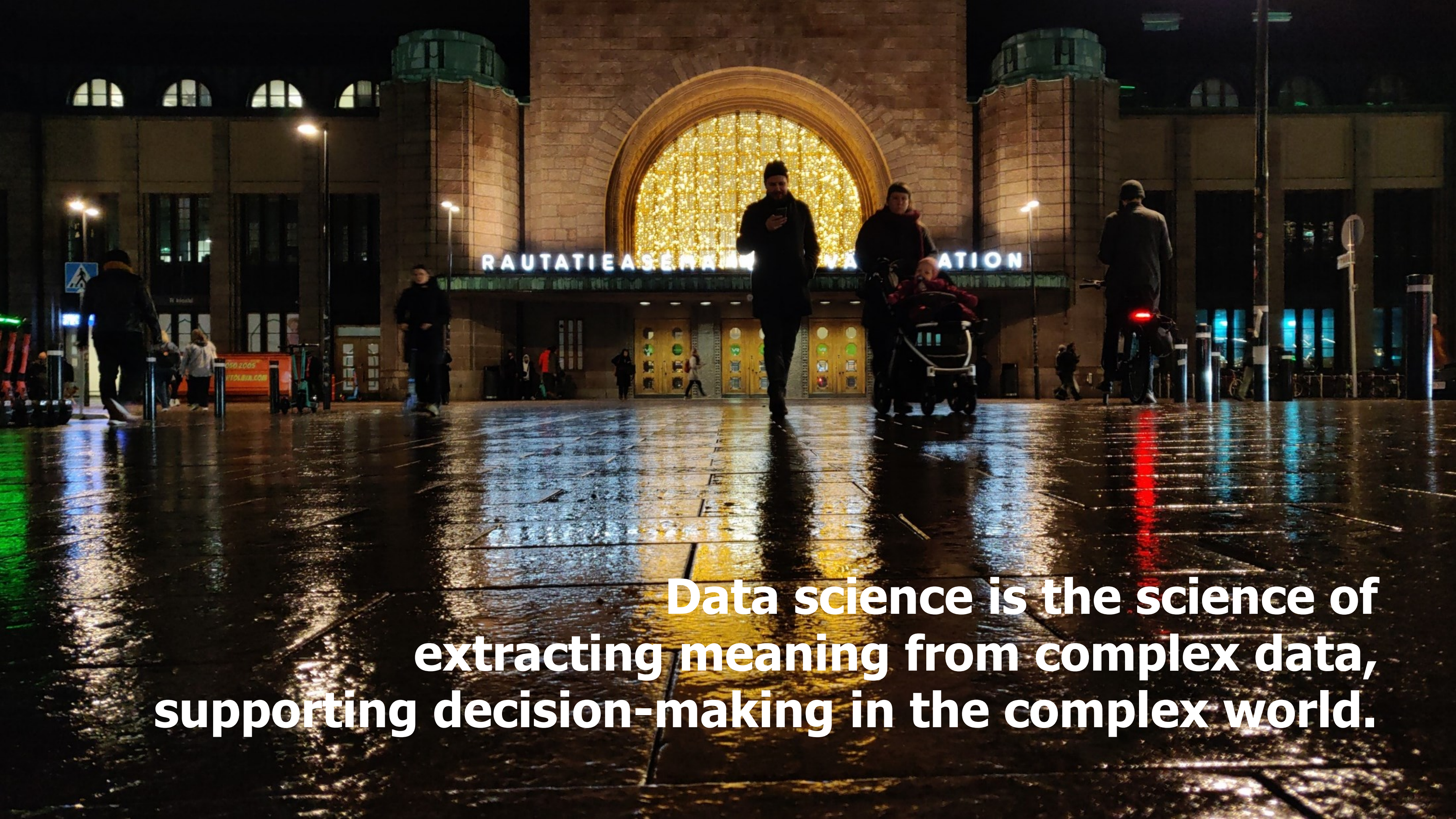


Source: https://xkcd.com/2560



Data science is the science of extracting meaning from complex data, supporting decision-making in the complex world.

Humanity relies on ecosystems

Image: TEEB Europe

… but environmental data science is not well-developed

(Blair et al. 2019)

Environmental data comes from a wide variety of sources

- Field campaigns
- Remote sensing
- Autonomous monitoring systems
- Citizen science
- Historical records
- Model outputs
- Data mining from social media etc.

- Heterogeneous in
  - Temporal resolution
  - Spatial scales
  - Reliability

- Many crucial organisms / processes / variables may still be missing

Keep in mind: A note from critical data studies

- Data are always interpretation: different choices may be made due to context and tradition
- Data lose meaning without their context
  - What is context, what is data?
  - Relevant context is not self-evidently clear → never fully incorporated in metadata
- Data are influenced by software, hardware, protocols, documentation, social choices

Neff et al. 2017. https://doi.org/10.1089/big.2016.0050

Challenge 2:

Understanding ecosystems

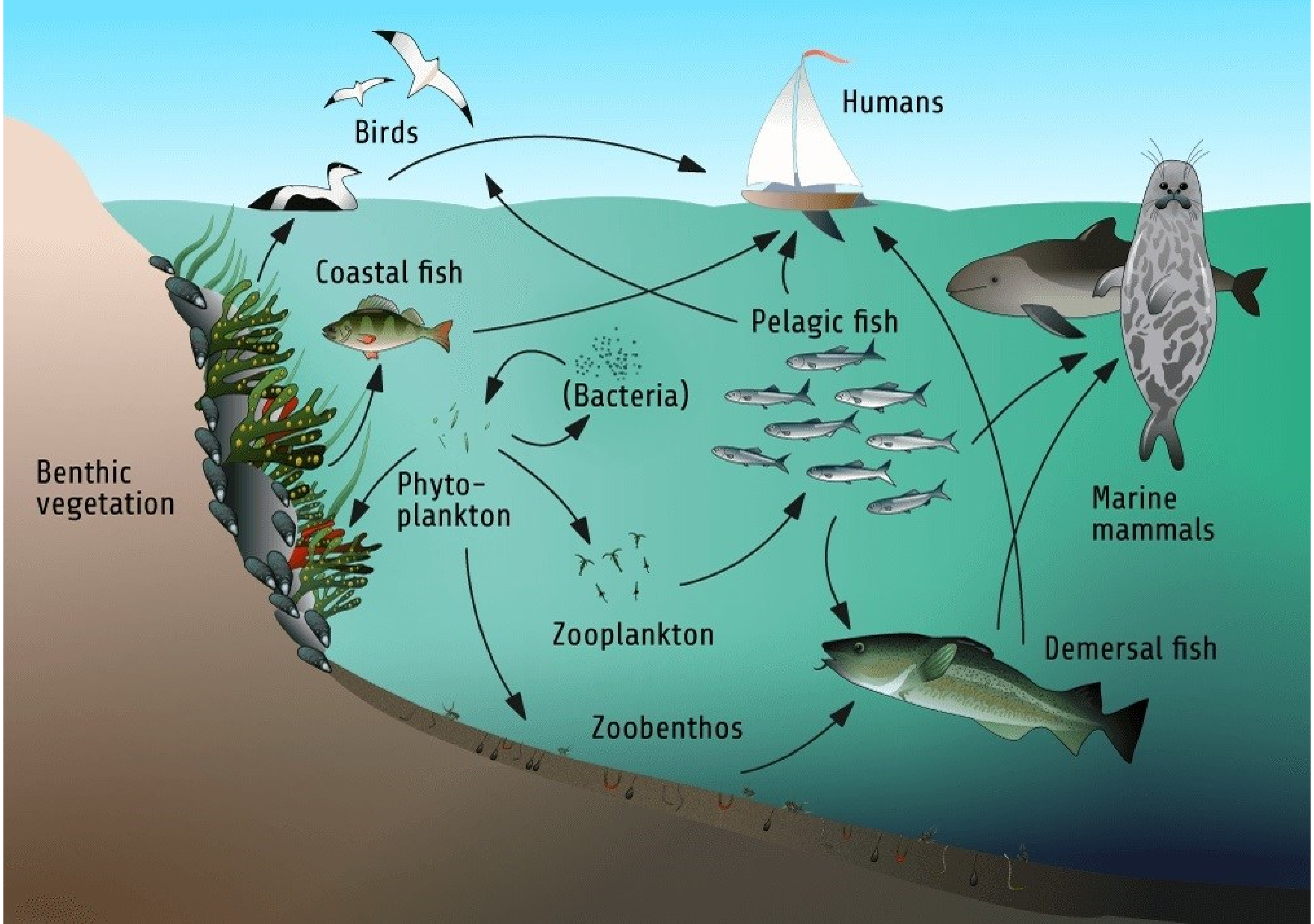


Image: HELCOM HOLAS II, Fig-1.3: Baltic Sea food web. Sebastian Dahlström.

Historical data: a fickle friend

Hydrobiologia (2013) 707:109–133
DOI 10.1007/s10750-012-1414-4

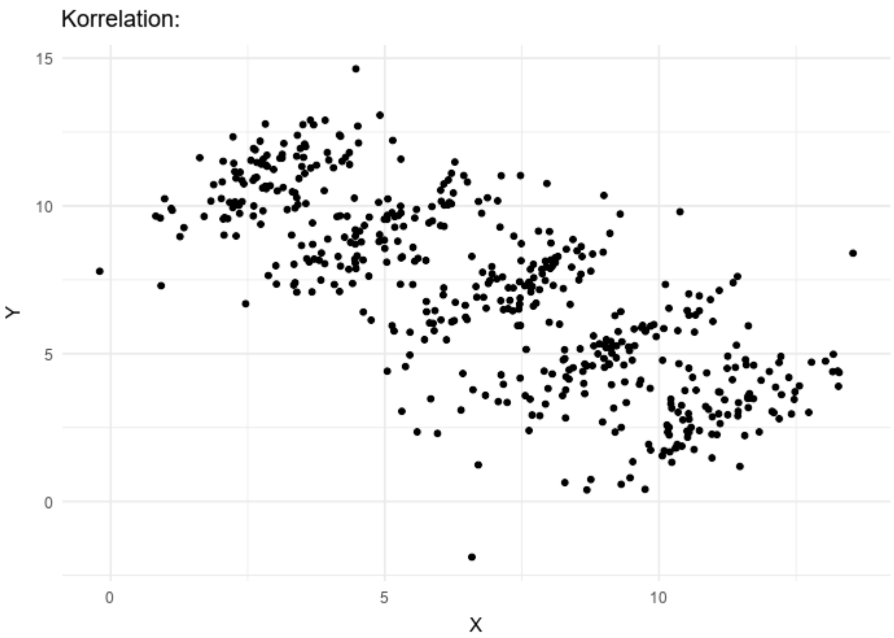
PRIMARY RESEARCH PAPER

The northern Baltic Sea phytoplankton communities in 1903–1911 and 1993–2005: a comparison of historical and modern species data

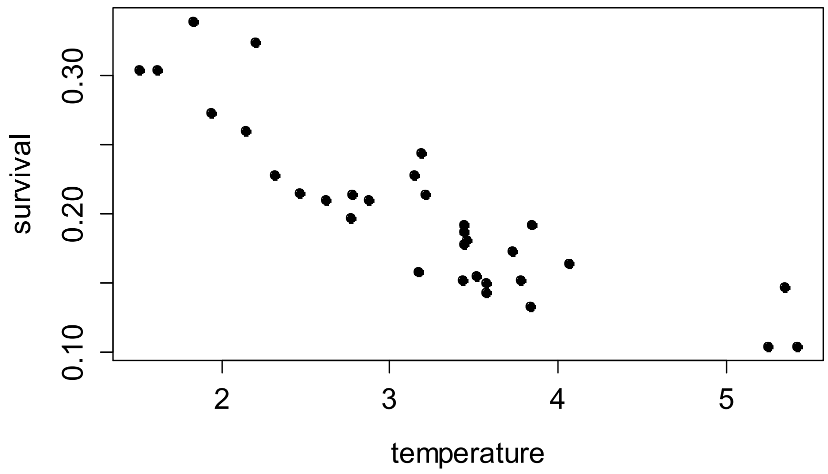
Heidi Hällfors · Hermanni Backer · Juha-Markku Leppänen · Seija Hällfors · Guy Hällfors · Harri Kuosa

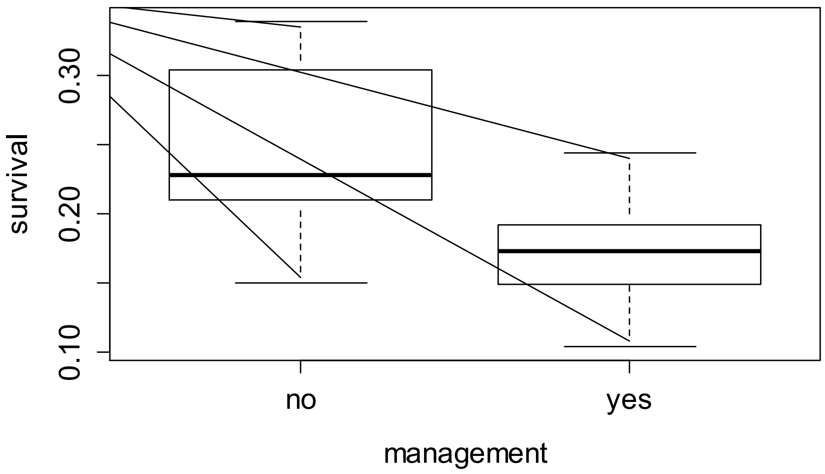
- Sampling equipment
- No information on preservation & analysis methods
- Nomenclature changes
- Identification issues

Correlations: Simpson’s paradox

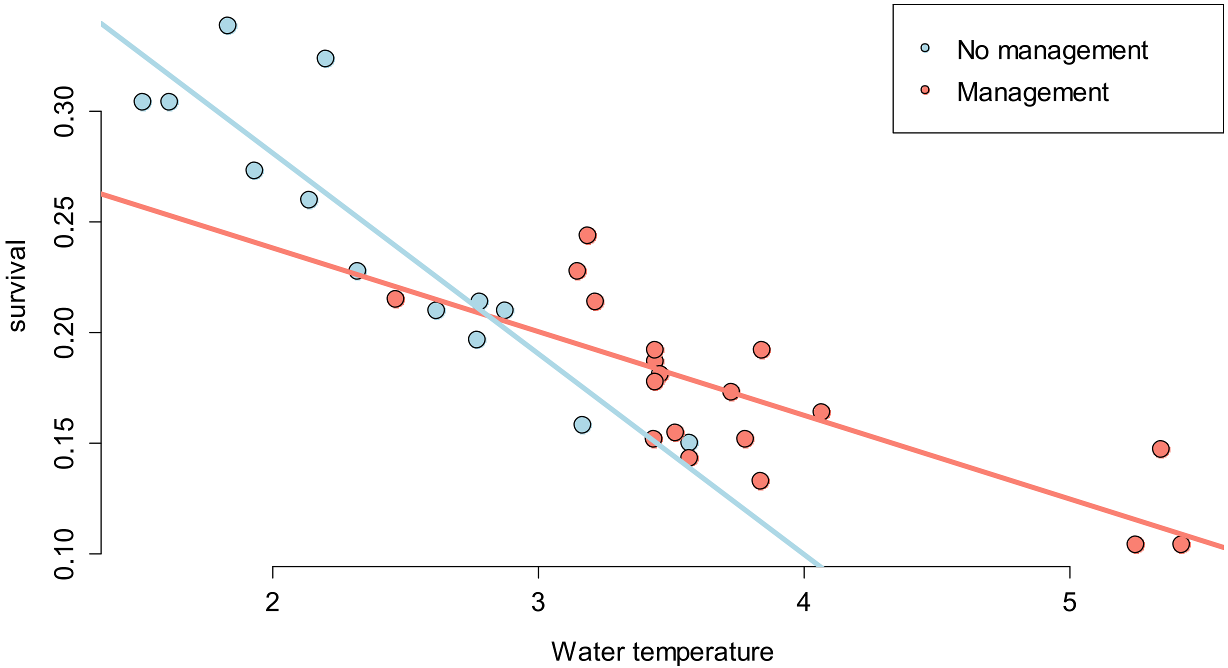


Simpson's paradox in ecology (1/2)





Simpson's paradox in ecology (2/2)



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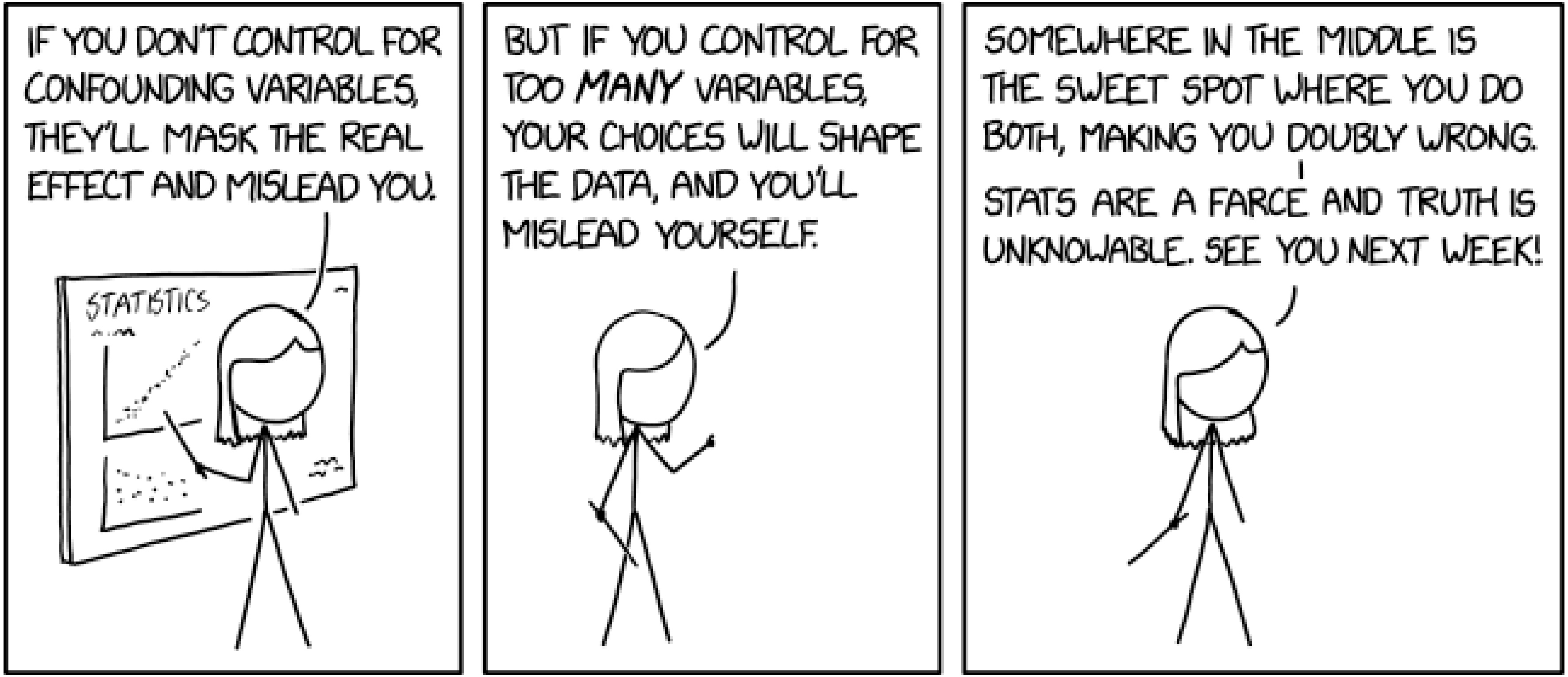
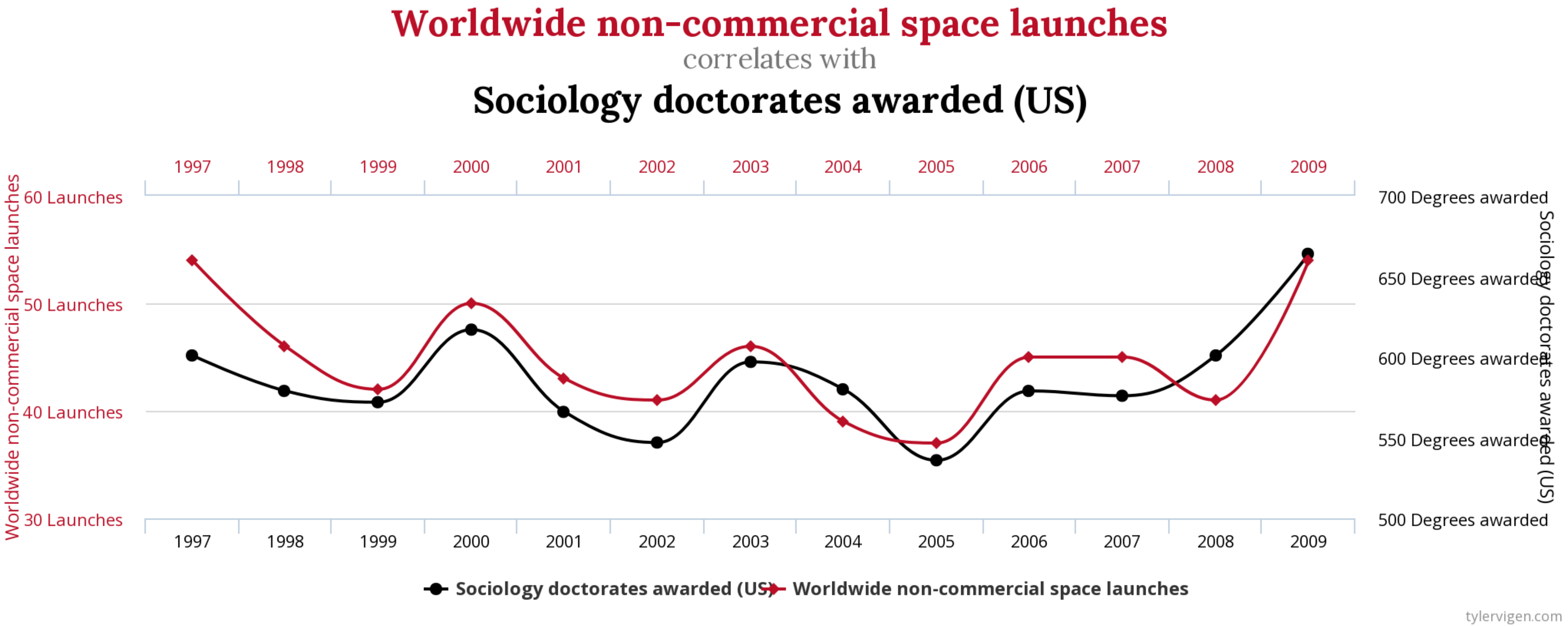


Source: https://xkcd.com/2560

Spurious correlations



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Challenge 3:

Understanding ecosystem recovery

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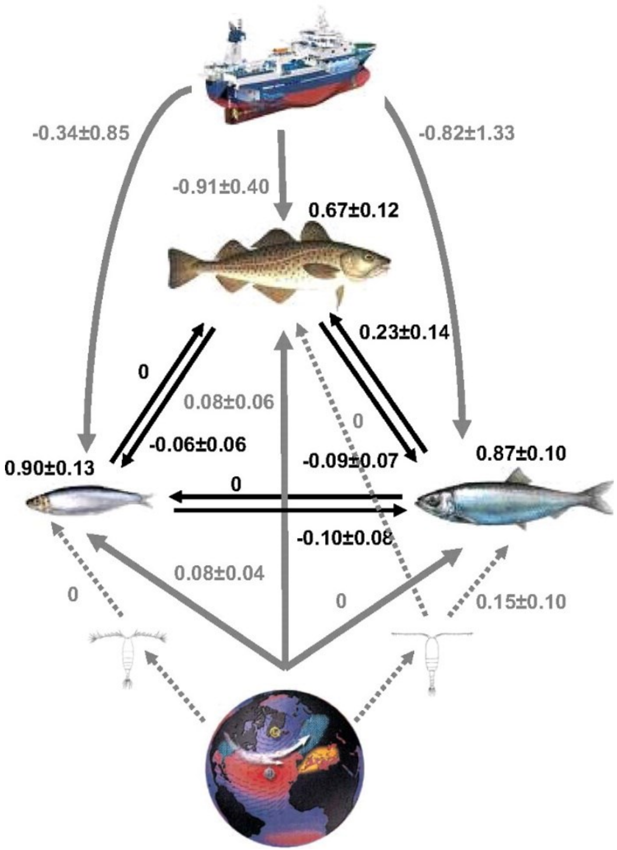
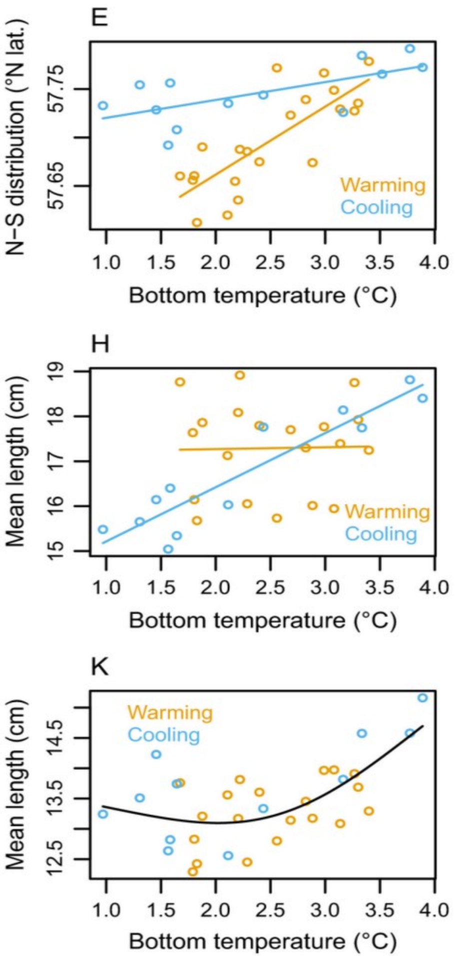
We try to understand ecosystems by modelling them



...but can we predict the future based on the past?

Image from:
Martin Lindegren, Christian Möllmann, Anders Nielsen, and Nils C. Stenseth
PNAS August 25, 2009 106 (34) 14722-14727; https://doi.org/10.1073/pnas.0906620106



Source: Michael A. Litzow, Mary E. Hunsicker: Early warning signals, nonlinearity, and signs of hysteresis in real ecosystems
Ecosphere, Volume: 7, Issue: 12, First published: 20 December 2016, DOI: (10.1002/ecs2.1614)

Hysteresis

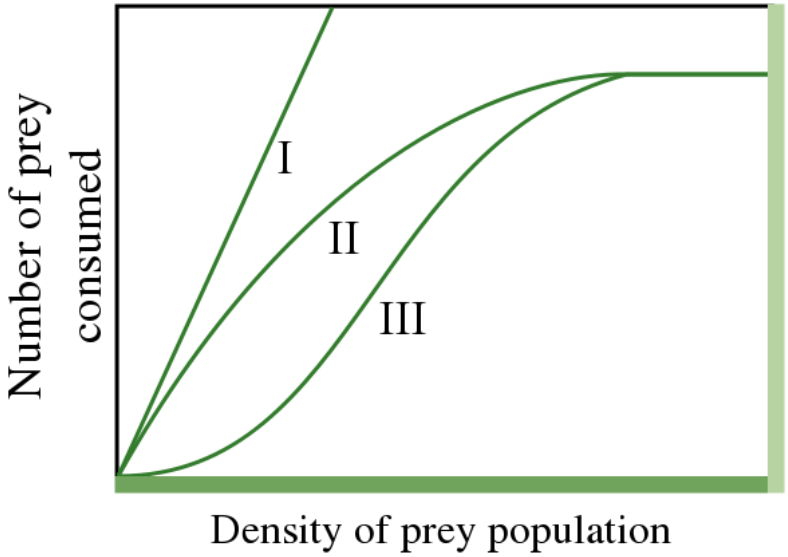
Response does not reverse its initial path after a perturbation is reversed

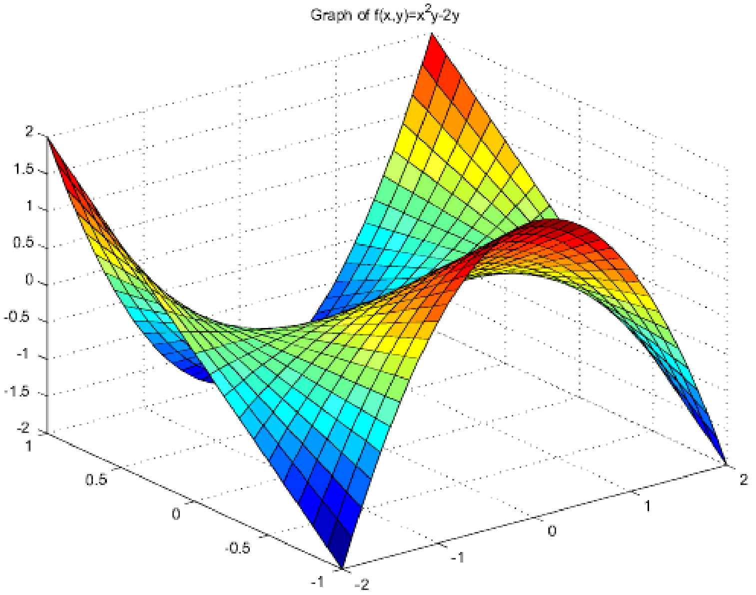
→ **Recovery does not follow the path of deterioration!**

May depend on feedback loops or different variables controlling the response in different states.

Formal tests for hysteresis are extremely difficult in observational systems (Schröder et al. 2005, Dudgeon et al. 2010, Faassen et al. 2015)

Ecosystem change





FunctionalResponsesGraph.jpg: Professor Moorcroft, derivative work: Petteri Aimonen, Public domain, via Wikimedia Commons

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Case study: Tracking change

Uusitalo, L. Tomczak, M.T., Müller-Karulis, B., Putnis, I., Trifonova, N., Tucker, A. 2018. Hidden variables in a Dynamic Bayesian Network identify ecosystem level change. Ecological Informatics 45: 9-15. https://doi.org/10.1016/j.ecoinf.2018.03.003

Maldonado, A.D., Uusitalo, L., Tucker, A., Blenckner, T., Aguilera, P.A., Salmerón, A. 2019. Prediction of a complex system with few data: Evaluation of the effect of model structure and amount of data with dynamic bayesian network models. Environmental Modelling & Software 118: 281-297. https://doi.org/10.1016/j.envsoft.2019.04.011

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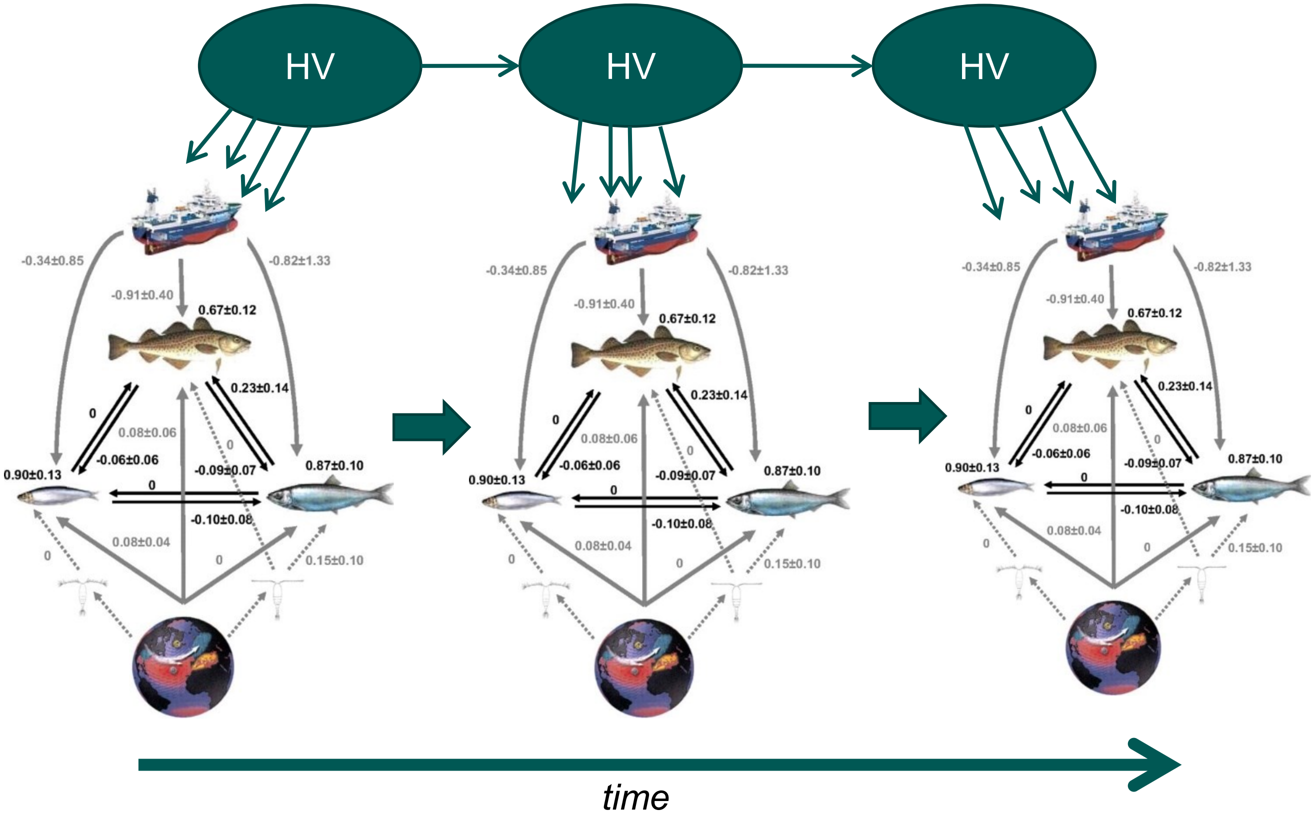
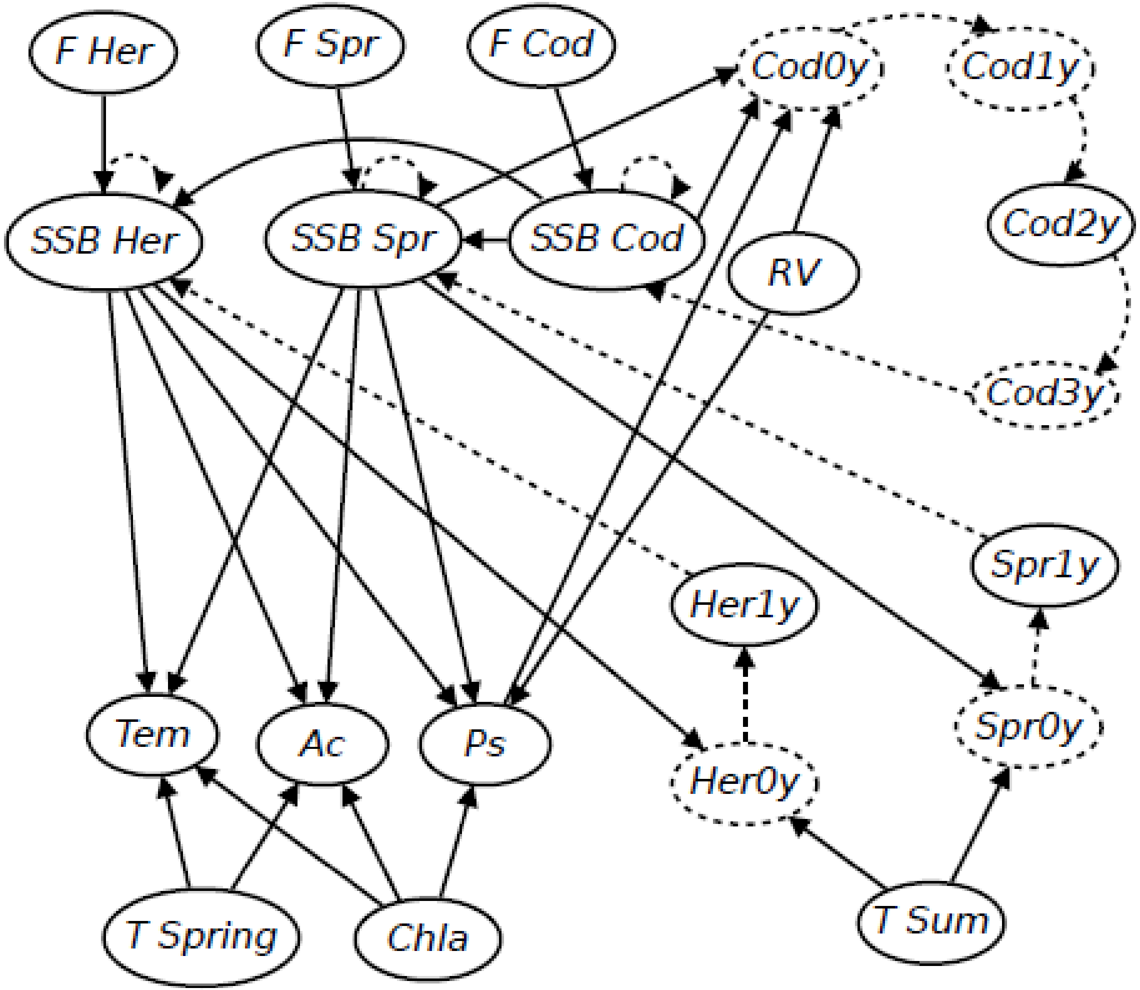
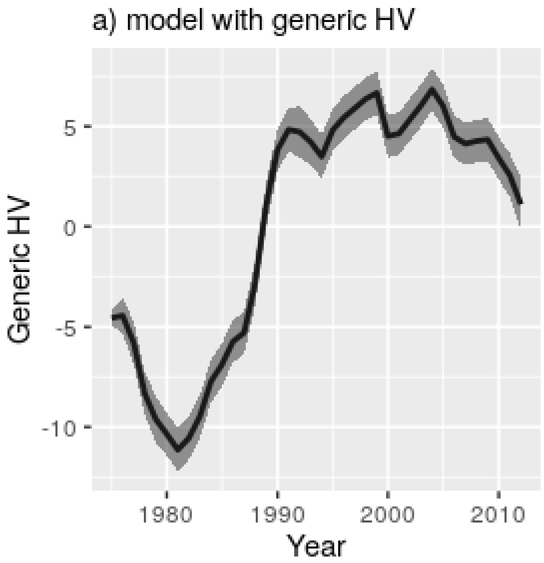


Food web image from:
Martin Lindegren, Christian Möllmann, Anders Nielsen, and Nils C. Stenseth
PNAS August 25, 2009 106 (34) 14722-14727; https://doi.org/10.1073/pnas.0906620106


F Her
F Spr
F Cod
Cod0y
Cod1y
SSB Her
SSB Spr
SSB Cod
RV
Cod2y
Cod3y
Spr1y
Her1y
Tem
Ac
Ps
Her0y
Spr0y
T Spring
Chla
T Sum

The hidden variables robustly detected the systemic change

- The result did not change with the exact model setup or when adding more data
- Hidden variable can be continuous (as in here) or discrete (alternate stable states)
- A lot of assumptions go also into this model…
- We need to be very careful not to under- or overparameterise!



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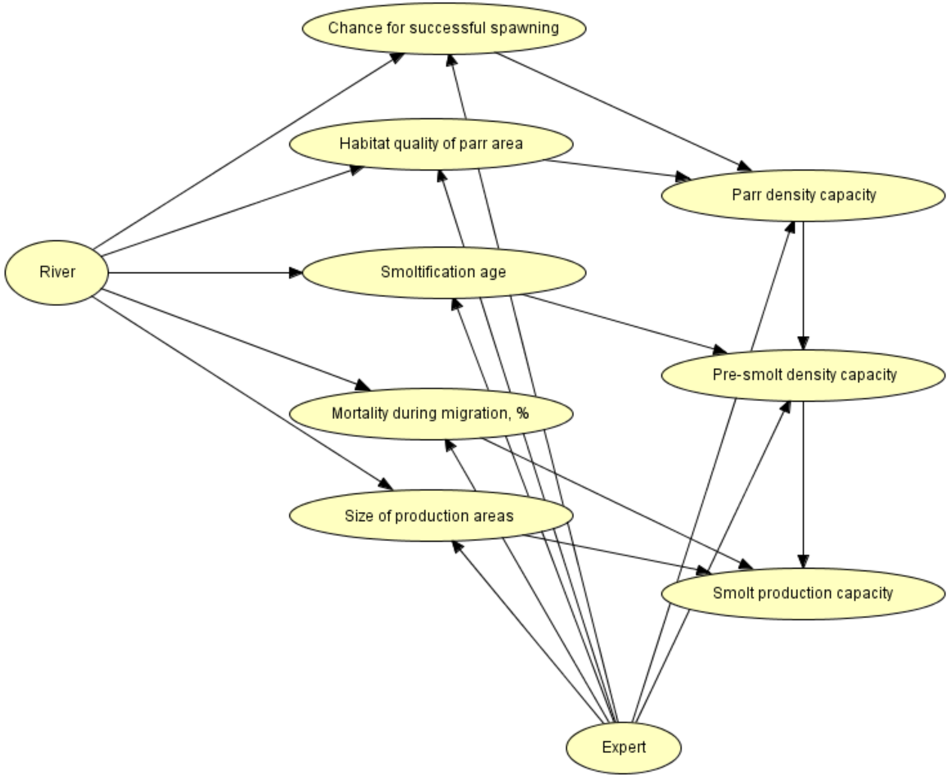
Case study: Predicting recovered state

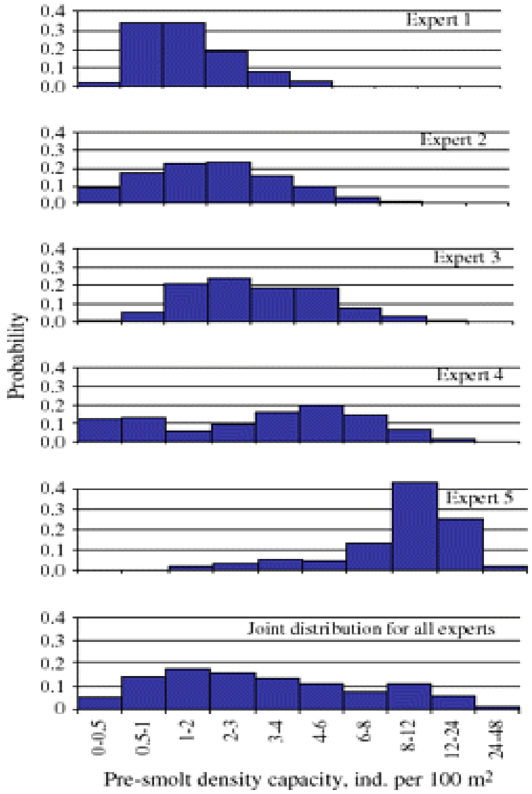
- Uusitalo, L., Kuikka, S., Romakkaniemi, A. 2005. Estimation of Atlantic Salmon Smolt Carrying Capacity of Rivers Using Expert Knowledge. ICES Journal of Marine Science 62(4):708-722. https://doi.org/10.1016/j.icesjms.2005.02.005



How many salmon can the rivers rear?

- Task: Estimate how many salmon juveniles could, at maximum, be reared in each of the rivers
- Problem: the maximum had not been reached during historical records
  - Extrapolating using equations was practically impossible
- Solution: Expert judgement!

The experts disagreed…



ICES J Mar Sci, Volume 62, Issue 4, 2005, Pages 708–722, https://doi.org/10.1016/j.icesjms.2005.02.005

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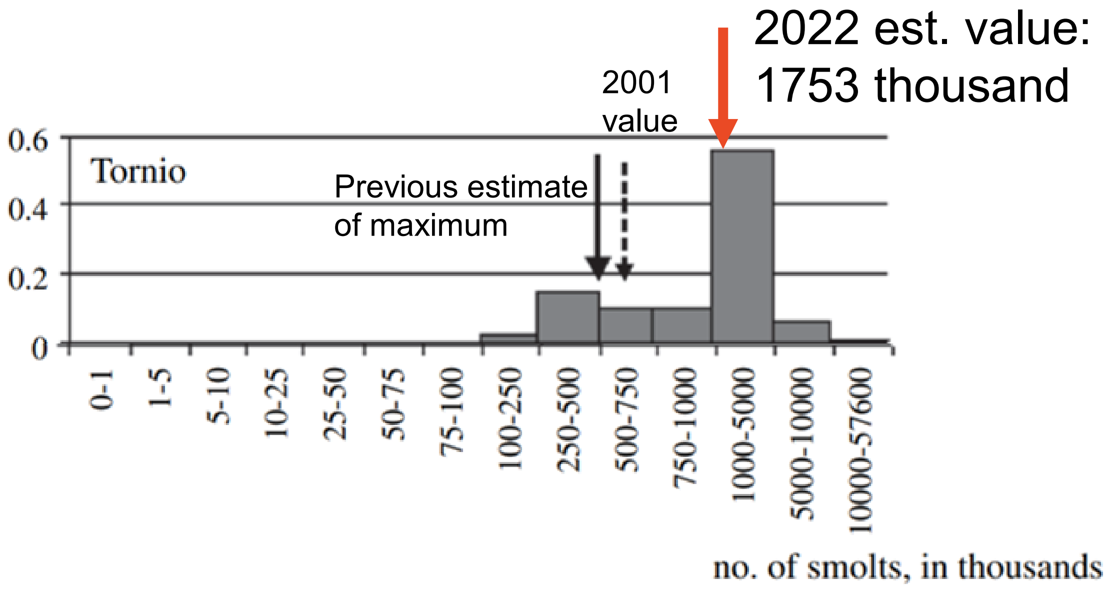
20 years later:



Reflections and recommendations

- Ecological knowledge and data analysis are both needed, and **collaboration** between experts in these domains is crucial!
- We need to be careful not to over- or underparameterise our models!
- Keep in mind what isn't in the data: Variables, habitats, context of the data collection, …

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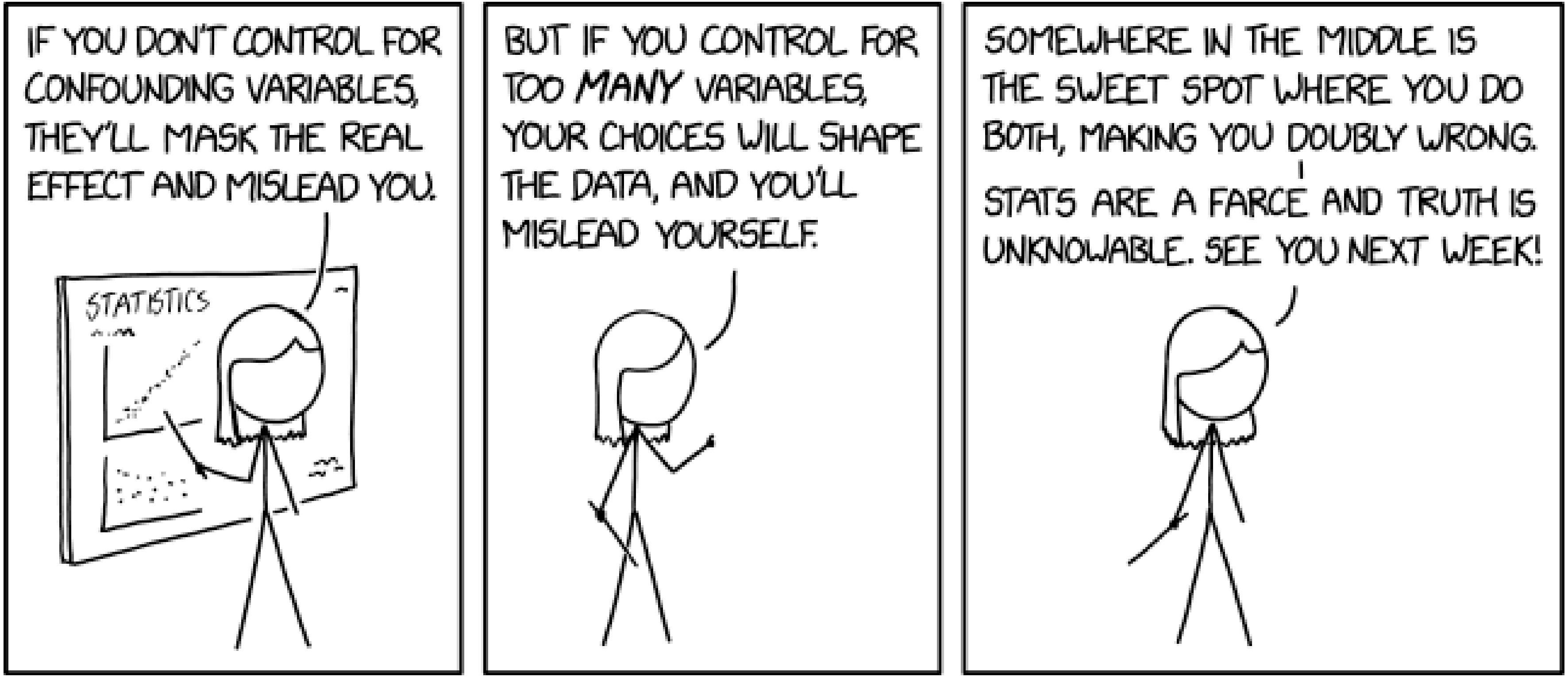

Source: https://xkcd.com/2560

Reflections and recommendations

- Ecological analyses are often used in management
  - → they affect people's opportunities (income, well-being)
  - → **Transparency and accountability are needed throughout the process!**
  - Systems have to be understandable, explainable, and verifiable
- **Clear communication about starting points, assumptions**

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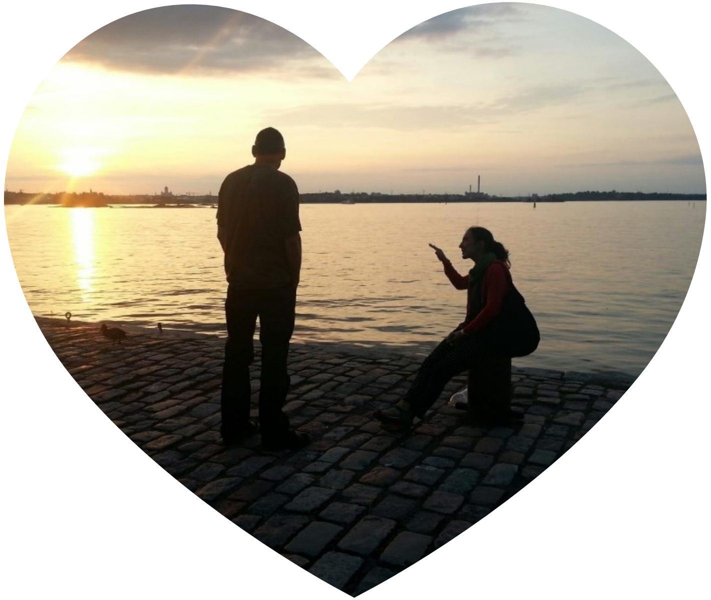
Thank you!



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