Extrapolating across levels of biological organization and how mechanistic models can help

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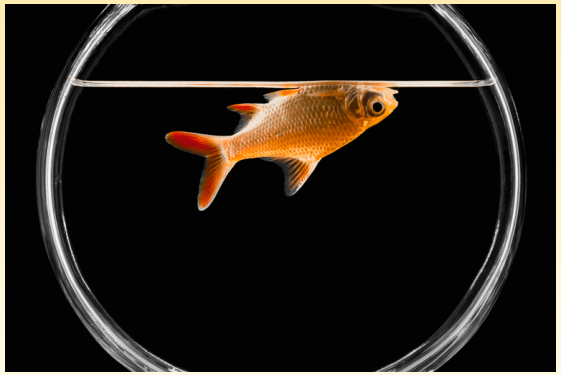
What is my research area?

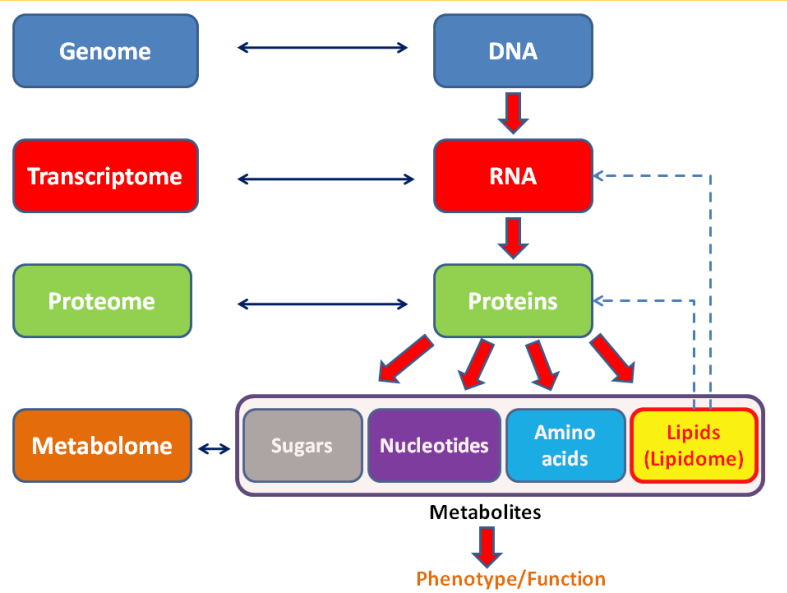
- (Aquatic) Ecology & Ecotoxicology
- Ecological Risk Assessment of Chemicals (and other stressors)
- Mechanistic modeling of stressor impacts

Exposure + **Toxicity** + **Ecology**



What challenges do we face?

What we measure

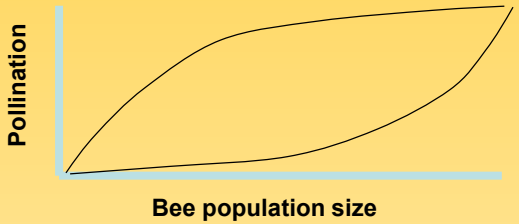


What we care about

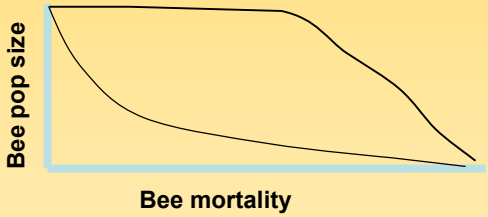
Models are needed to make these links!

We can't assume responses at different levels are directly proportional because biological responses are highly nonlinear and context dependent

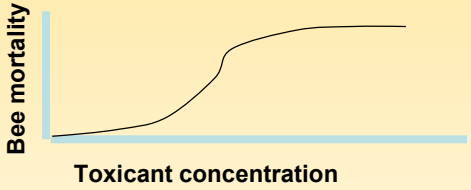
And population properties are often not simple predictors of ecosystem processes or services.



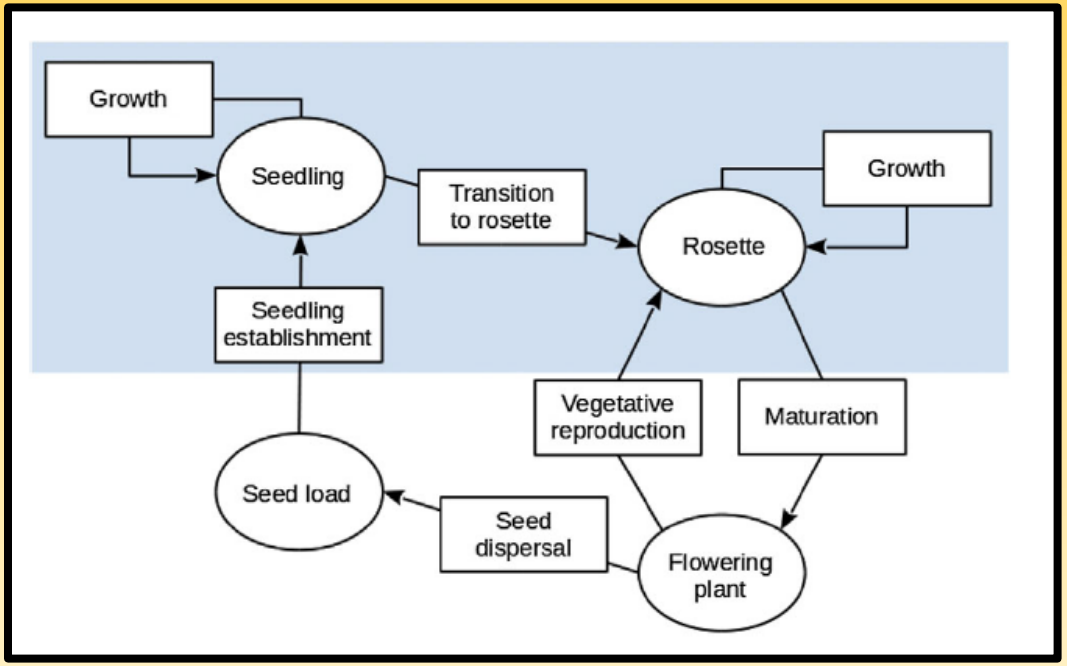
But mortality (or survival or growth) are not linearly related to population dynamics.

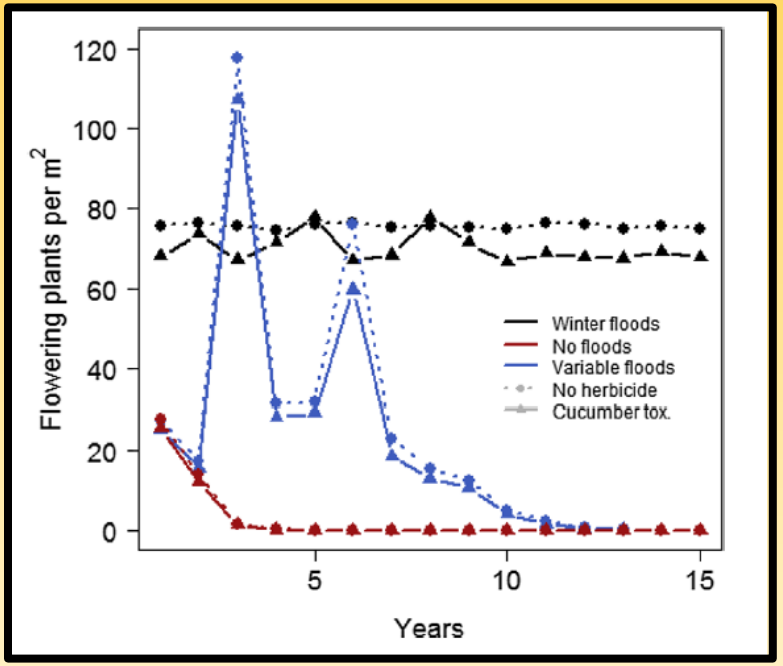


What we measure: Individual toxicity



Model of the threatened *Boltonia decurrens* to explore effects of flooding, competition, and herbicides on its population dynamics.





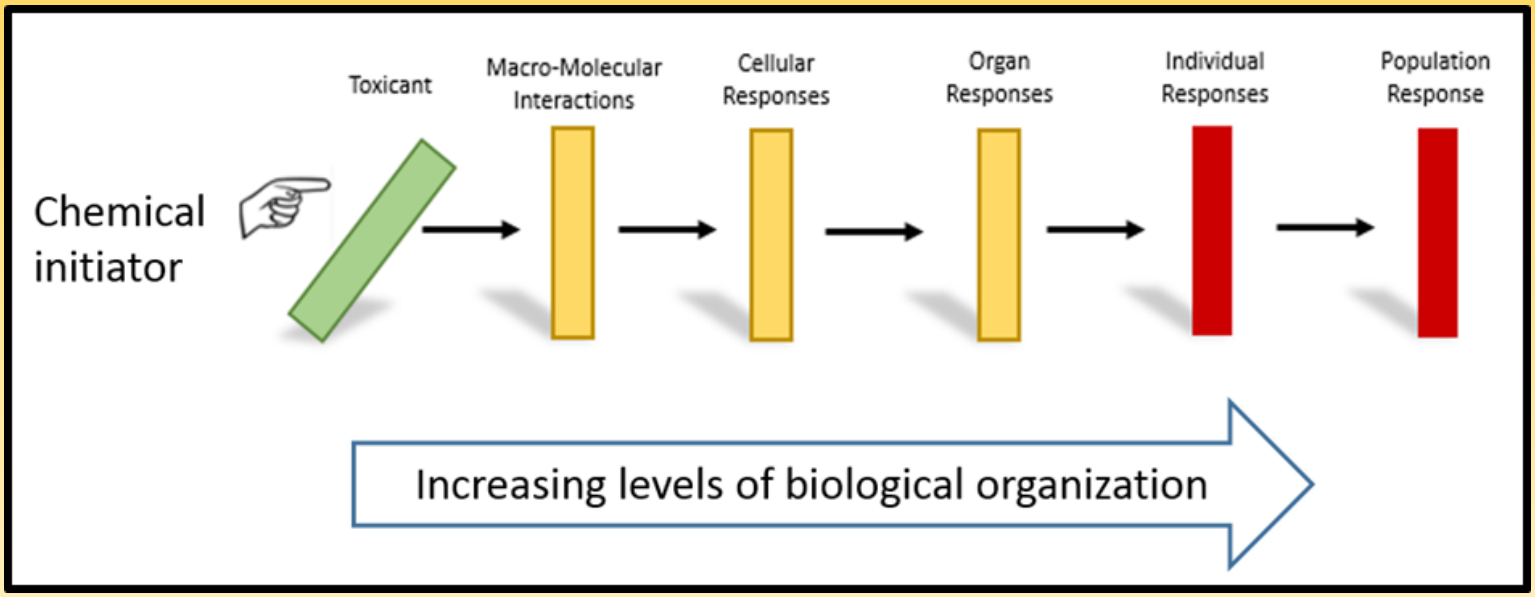
Flooding was essential for species persistence; herbicide effects relatively minor, but could shift competitive balance between *B. decurrens* and other species.

Schmolke et al. 2017. ET&C 36: 480-491

How can mechanistic models help?

- More realistic spatial & temporal variability in exposure
- Facilitate assessments over relevant scales
- Better extrapolation of effects among species
- Can incorporate behavior (e.g., avoidance), dispersal, and life history
- Can link what we measure in experiments more directly to protection goals
- Explore risk scenarios & management alternatives cost effectively
- Reduce animal testing without losing the ecology – in theory

Example – Adverse Outcome Pathway Models

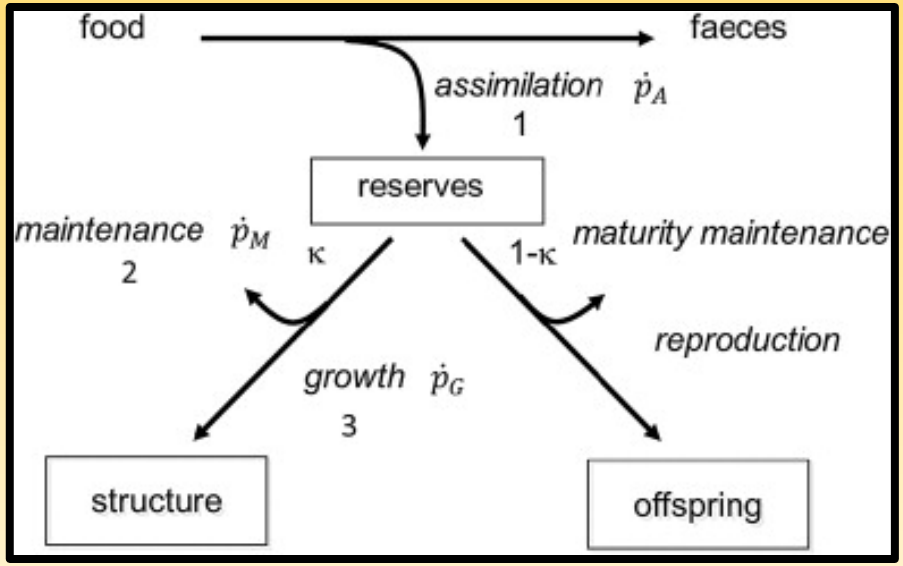


Note: Most AOPs are still qualitative descriptions without underlying equations – but this is changing

Ankley et al. 2010. ET&C 29: 730-741

Example – Dynamic Energy Budget Models

Dynamic Energy Budget theory
(Bas Kooijman 2010)

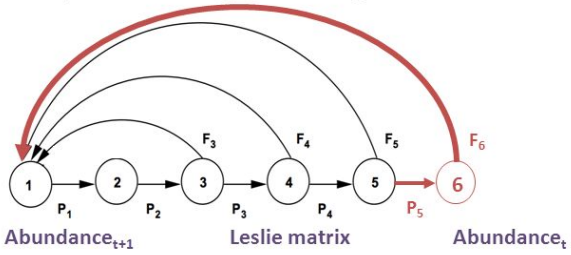


- Describes energy acquisition & allocation
- Generic rules obey conservation of mass & energy
- Facilitates inter-species comparisons
- Can be applied across a wide range of stressors

Example – Matrix Population Models

How does matrix multiplication work?

Example 2: A Leslie matrix for an organism living 6 years with 3-6 year olds reproducing:



Abundance_{t+1} = Leslie matrix × Abundance_t

$$\begin{bmatrix} N_{1,t+1} \\ N_{2,t+1} \\ N_{3,t+1} \\ N_{4,t+1} \\ N_{5,t+1} \\ N_{6,t+1} \end{bmatrix} = \begin{bmatrix} 0 & 0 & F_3 & F_4 & F_5 & F_6 \\ P_1 & 0 & 0 & 0 & 0 & 0 \\ 0 & P_2 & 0 & 0 & 0 & 0 \\ 0 & 0 & P_3 & 0 & 0 & 0 \\ 0 & 0 & 0 & P_4 & 0 & 0 \\ 0 & 0 & 0 & 0 & P_5 & 0 \end{bmatrix} \times \begin{bmatrix} N_{1,t} \\ N_{2,t} \\ N_{3,t} \\ N_{4,t} \\ N_{5,t} \\ N_{6,t} \end{bmatrix}$$

Note: we have to use matrix multiplication!

Hal Caswell 2001

- Population divided into groups based on age, stage, or size
- Data collected on survival, fertility, growth
- Can add stochasticity, as well as spatial structure (metapopulation models)
- Very widely used

Example – Individual-Based Models

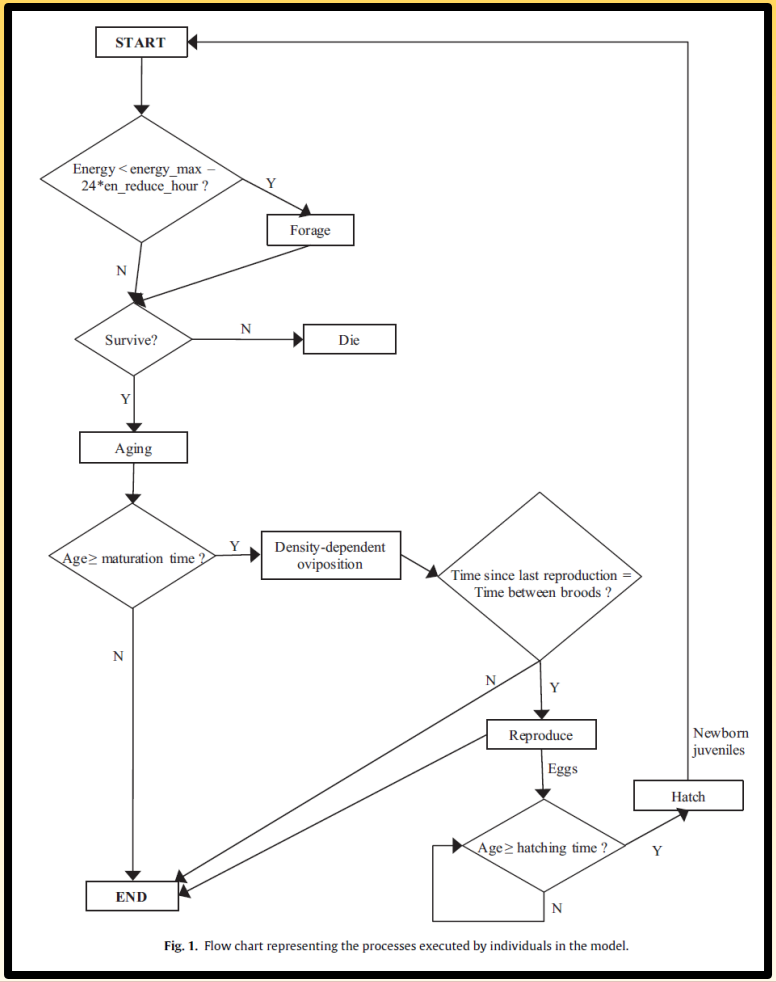


Fig. 1. Flow chart representing the processes executed by individuals in the model.

- Considers all individuals in a population explicitly
- Population dynamics emerge from interactions of individuals with each other & the environment
- Very flexible & can be made very realistic
- Transparency reduces with increasing complexity

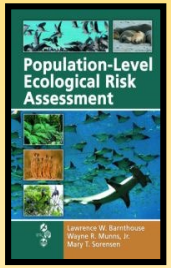
Meli et al. 2013. Ecol Mod 250: 338-351

Limitations & Obstacles

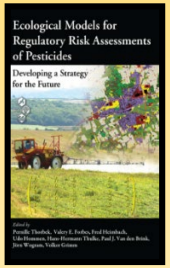
- Models cannot identify protection goals or define what is an acceptable impact
- Time, effort, and data needs for model development can be substantial
- Perception that models increase uncertainties (Not true!)
- Lack of transparency can breed mistrust
- Validation needs to be approached with care

There has been much progress in developing mechanistic effect models for ERA

2003



2007



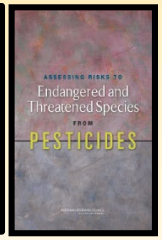
2008

2009

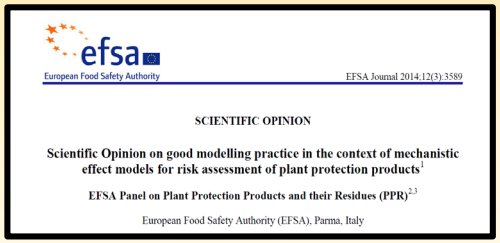
2009 - 2014

2012 - 2013

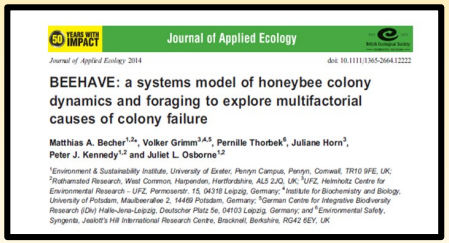
2013



2014

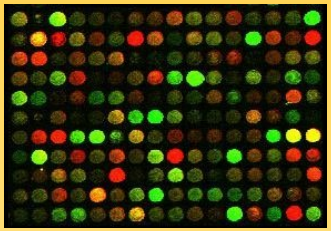
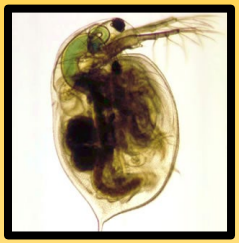


2015



Now

Gaps in knowledge & practice


- **Parameterizing the models has highlighted how much basic information we are lacking for most species.**
  - **Strategic and prioritized gaps will need to be filled**
- **The modeling tools exist, but we lack an overarching framework for incorporating them into the regulatory process.**
  - **This is work in progress**
- **Increasing emphasis on high throughput tools generates more data that are further removed from protection goals.**
  - **Just because we can measure it, doesn't mean it's useful**

NIMBioS

National Institute for Mathematical and Biological Synthesis

Predictive Models for Ecological Risk Assessment

A NIMBioS Investigative Workshop

April 28-30, 2014

NIMBioS at the Univ. of Tennessee, Knoxville

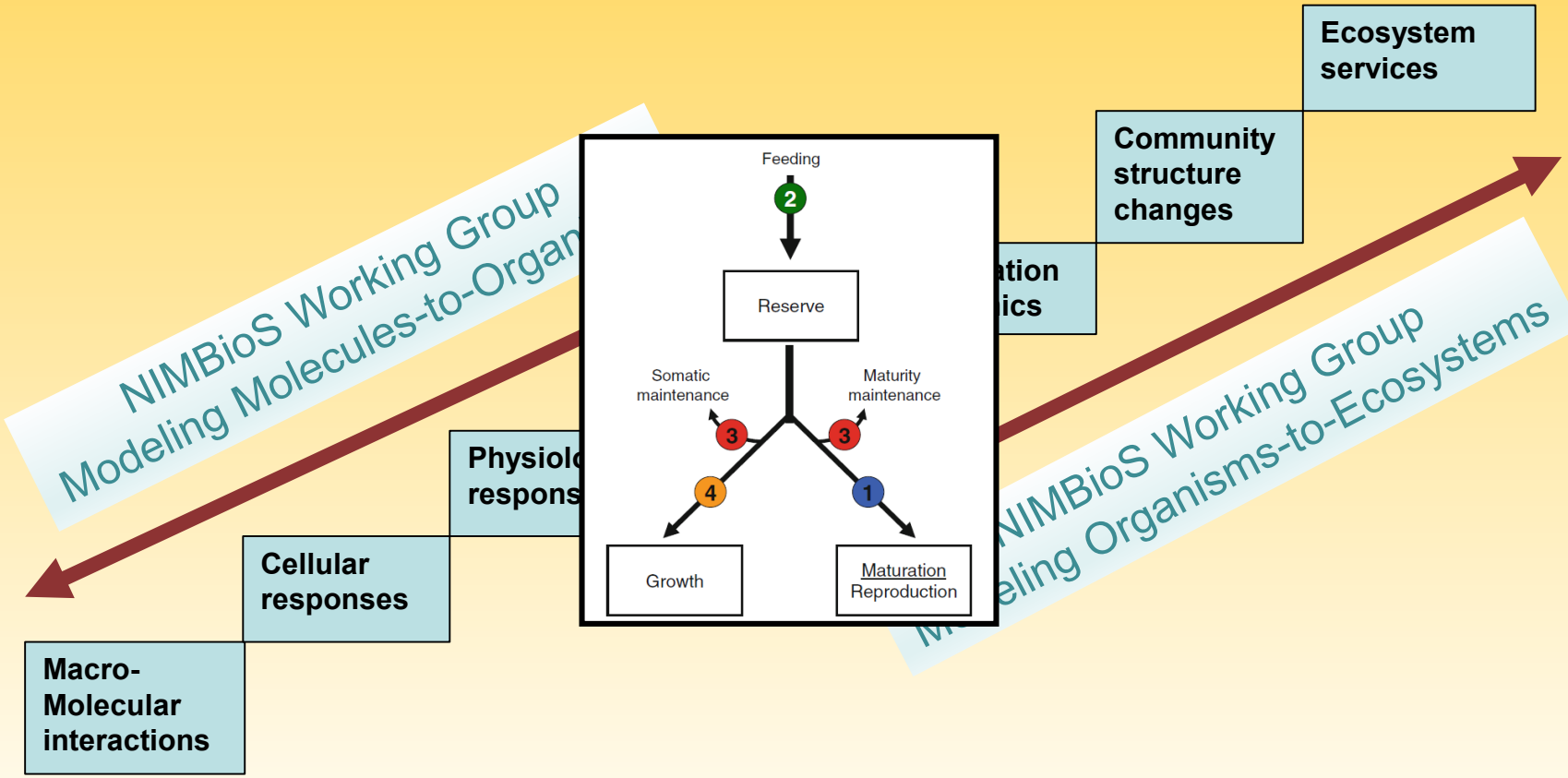
Organisms-to-Ecosystems WG

Mtg. 3 participants (L to R): Christopher Salice, Andrew Kanarek, Richard Rebarber, Yetta Jager, Roger Nisbet, Virginie Ducrot, Rob Pastorok, Valery Forbes, Bjorn Birnir, Pernille Thorbek, Randy Bruins, Nika Galic. (Kneeling): Kristina Garber, Steve Railsback.

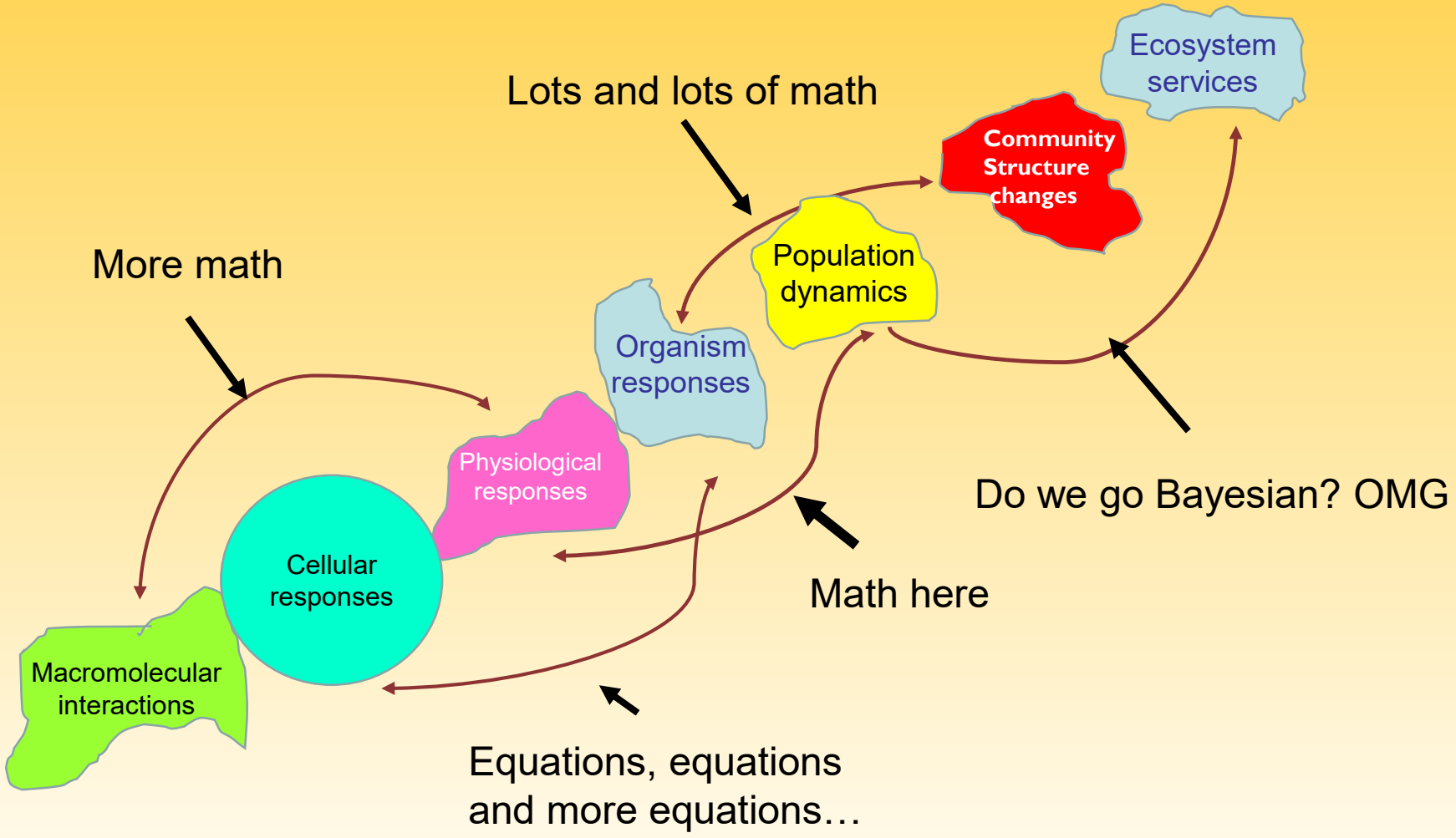
Molecules-to-Organisms WG

Mtg. 2 participants (L to R): Natalia Garcia-Reyero, Chris Remien, Roger Nisbet, Andre Gergs, Angie Peace, Cheryl Murphy, Konstadia (Dina) Lika, Diane Nacci, Philipp Antczak, Irv Schultz, Teresa (Terry) Mathews, Karen Watanabe.

Goals of NIMBioS WGs



The reality is more like this



Organisms-to-Ecosystem Services Framework

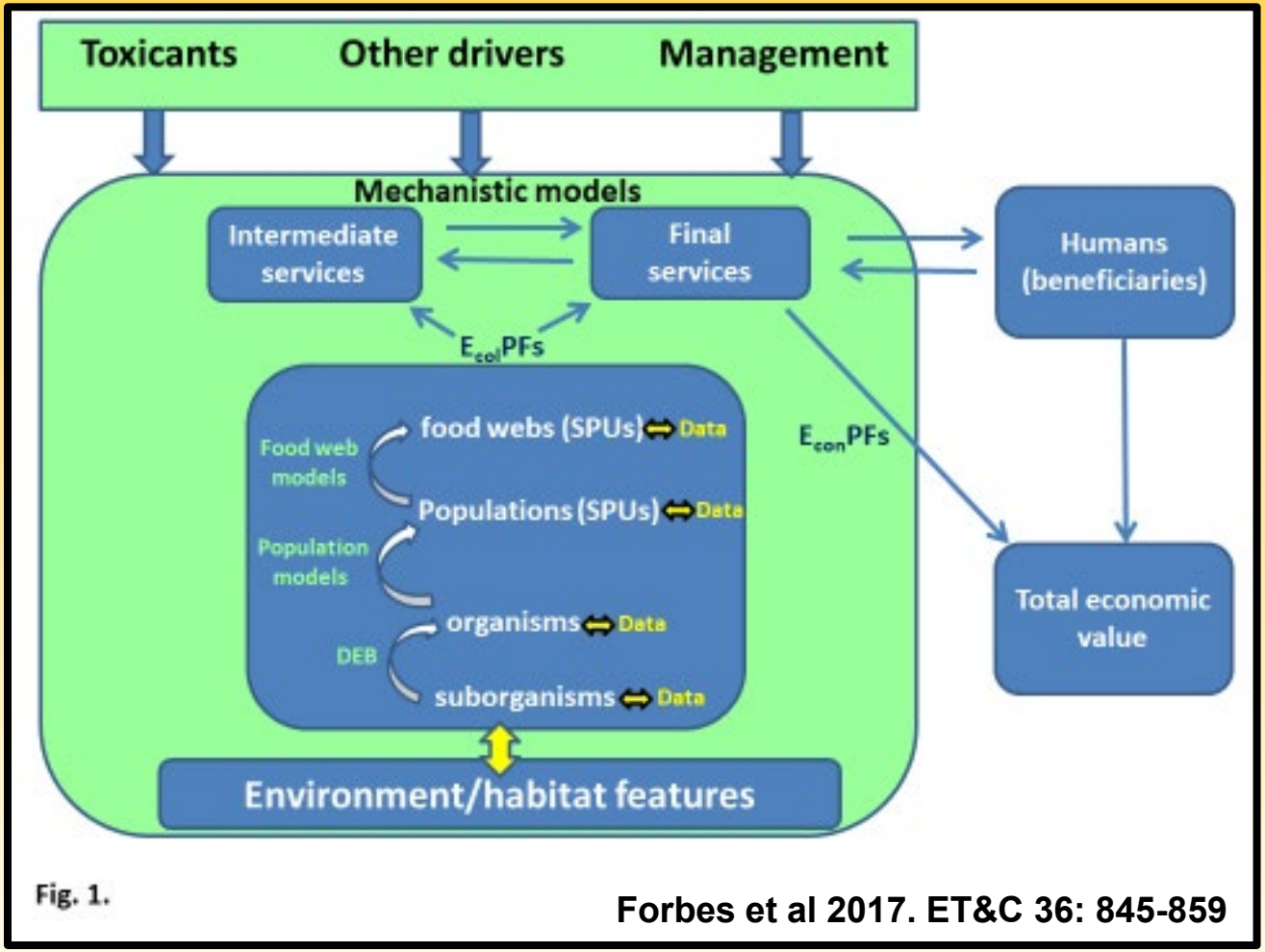


Fig. 1.

Forbes et al 2017. ET&C 36: 845-859

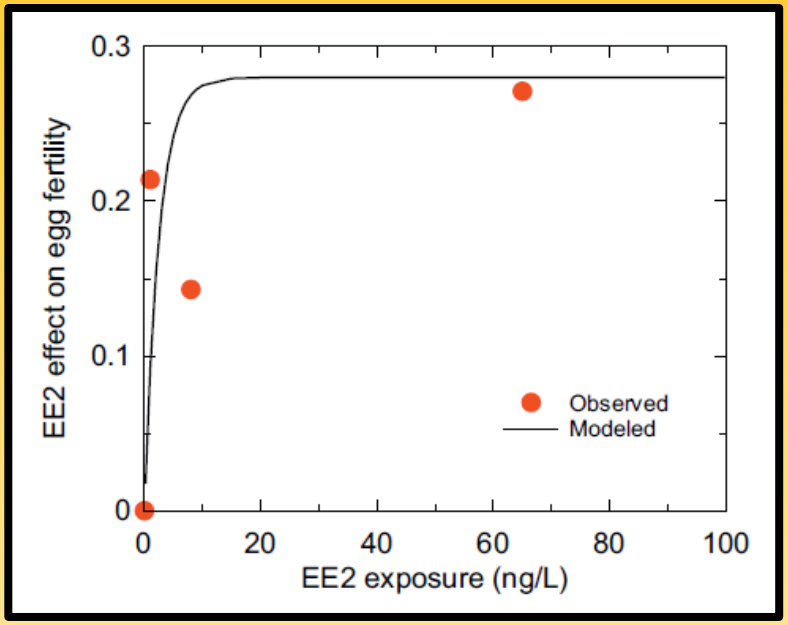
Case Study Approach:

Mountain Stream

- ES: catchable fish; presence of fish
- Stressor: Ethynyl estradiol (EE2)
- Model: inSTREAM IBM

Midwest Reservoir

- ES: clear water; catchable fish
- Stressor: Insecticide
- Model: AQUATOX multi-species ecosystem model

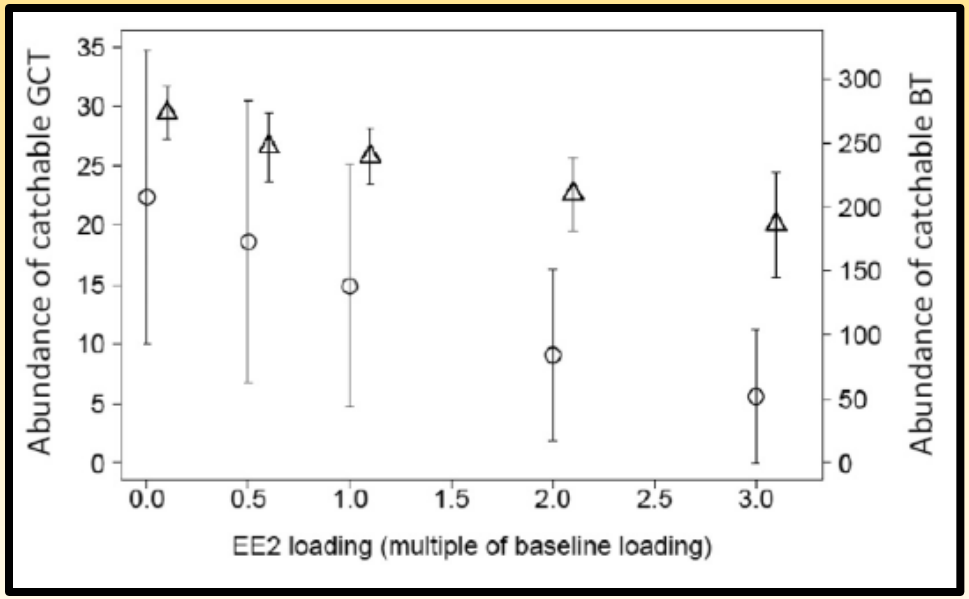


inSTREAM simulates spatiotemporal variability In habitat features, food, and predation risk.

Individual fish select habitat, grow, survive, and spawn.

Exposure of male trout to EE2 reduces fertilization success.

- BT are more abundant than GCT
- GCT are more sensitive to EE2
- Protecting GCT from EE2 is facilitated by managing BT



Forbes et al. 2017. STOTEN 682: 426-436

Fish species differed in their response to insecticide exposure due to differences in sensitivity and effects mediated through the food web.

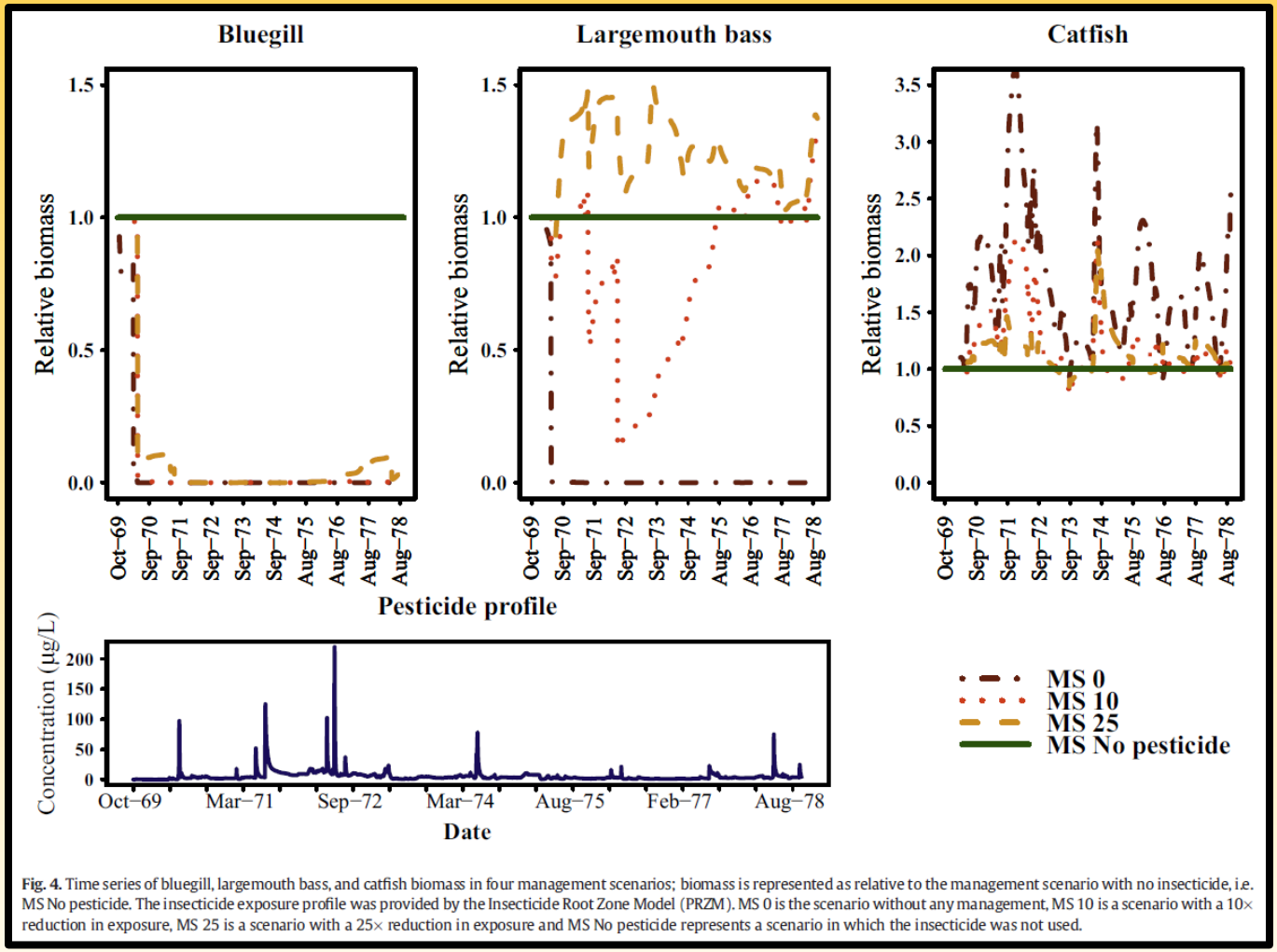
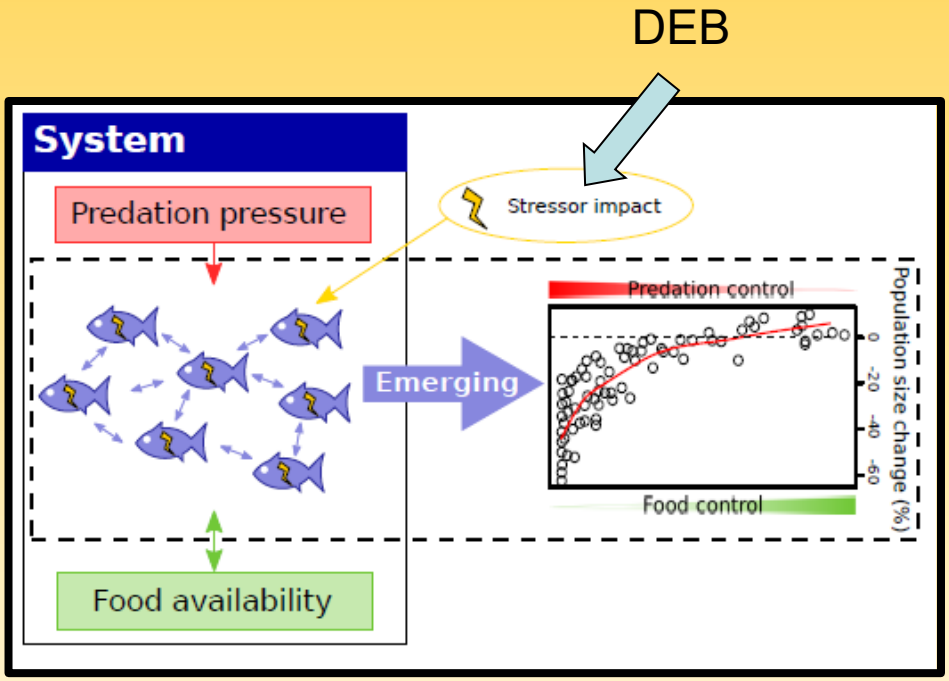


Fig. 4. Time series of bluegill, largemouth bass, and catfish biomass in four management scenarios; biomass is represented as relative to the management scenario with no insecticide, i.e. MS No pesticide. The insecticide exposure profile was provided by the Insecticide Root Zone Model (PRZM). MS 0 is the scenario without any management, MS 10 is a scenario with a 10× reduction in exposure, MS 25 is a scenario with a 25× reduction in exposure and MS No pesticide represents a scenario in which the insecticide was not used.

Galic et al. 2019. STOTEN 682: 426-436

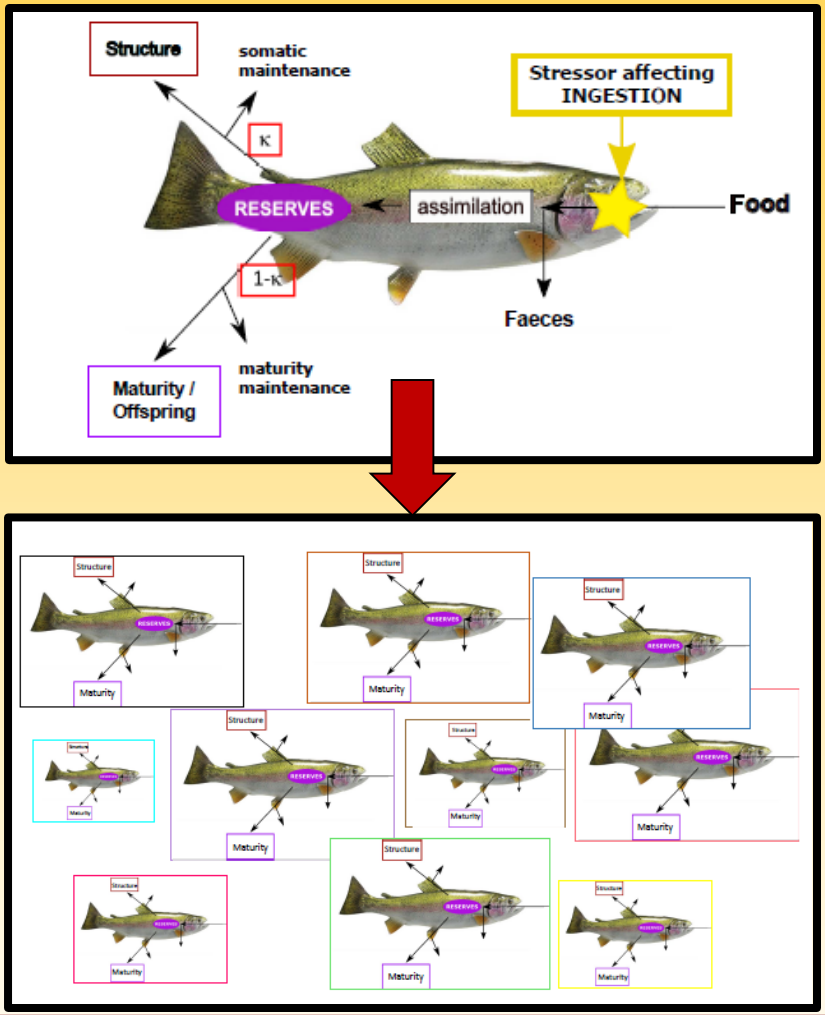
Ongoing work – Maxime Vaugeois



Vaugeois et al. submitted.

- What are the population-level impacts of stressors that affect an individual's metabolism (growth, reproduction, maintenance, assimilation)?
- Do the impacts differ between top-down and bottom-up controlled populations?

Ongoing work – Chiara Accolla



- How do sublethal effects on metabolism affect growth & reproduction in 3 trout species?
- To what extent are the individual-level responses indicative of population responses?

Accolla et al. in press. STOTEN

Ongoing work – Pamela Rueda-Cediel & Adrian Parr-Moore

816 species listed in US

90 species listed in US

- How can we fill demographic data gaps to develop models for listed species (no data!)?
- Can we identify particular traits that make species more/less vulnerable to stressors?
- Can we develop generic models to represent groups of similar species?

Stuff I learned the hard way in these kinds of collaborations

- Need to have an agreed lead for each collaborative team & deliverables/deadlines for each person.
- Regular (monthly?) conference calls are a must.
- Several-day in-person meetings can be effective if planned carefully.
- Conference presentations & proposal deadlines can be powerful incentives.
- Each project has to be someone's priority.
- Start with many project ideas, accepting that some (most?) won't make it.

Acknowledgements

- g2p2pop RCN organizers for inviting me.
- Current and past lab members for their great work.
- Numerous collaborators who have inspired my thinking on these issues over the years.