The impact of multiple environmental stressors on phytoplankton communities

Mark Holmes
Frederik De Laender

Biodiversity worldwide threatened by multiple environmental stressors

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These may produce non-additive effects when combined

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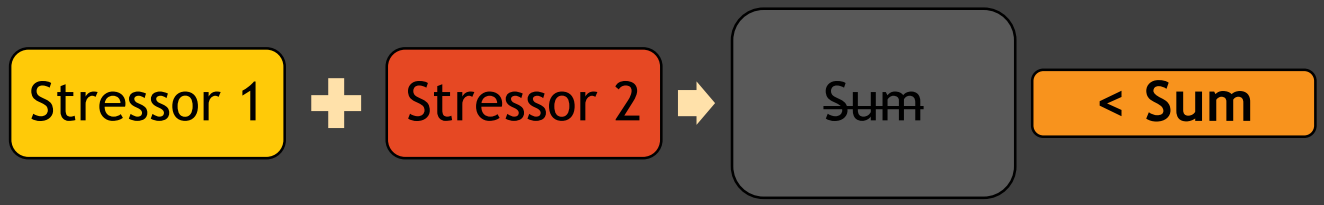
We may expect this:

Biodiversity worldwide threatened by multiple environmental stressors

These may produce non-additive effects when combined

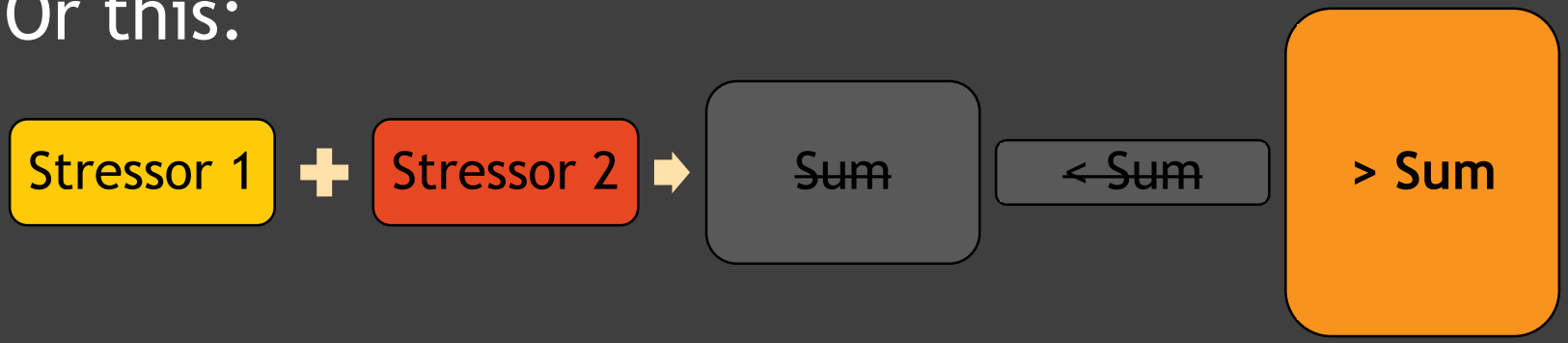
But find this:



Biodiversity worldwide threatened by multiple environmental stressors

These may produce non-additive effects when combined

Or this:



Non-additive interactions considered "ecological surprises"

Despite this, additive interactions are relatively uncommon in nature

> "we synthesized 171 studies that manipulated two or more stressors in marine and coastal systems and found that cumulative effects in individual studies were **additive (26%)**, **synergistic (36%)**, and **antagonistic (38%)**" Crain et al. 2008

Non-additive interactions considered "ecological surprises"

Despite this, additive interactions are relatively uncommon in nature

"Surprises" related to stressor interactions

Non-additive interactions considered "ecological surprises"

Despite this, additive interactions are relatively uncommon in nature

"Surprises" related to stressor interactions

Does the total number of stressors matter?

Can non-additivity occur without stressor interactions?

Are interactions so important?

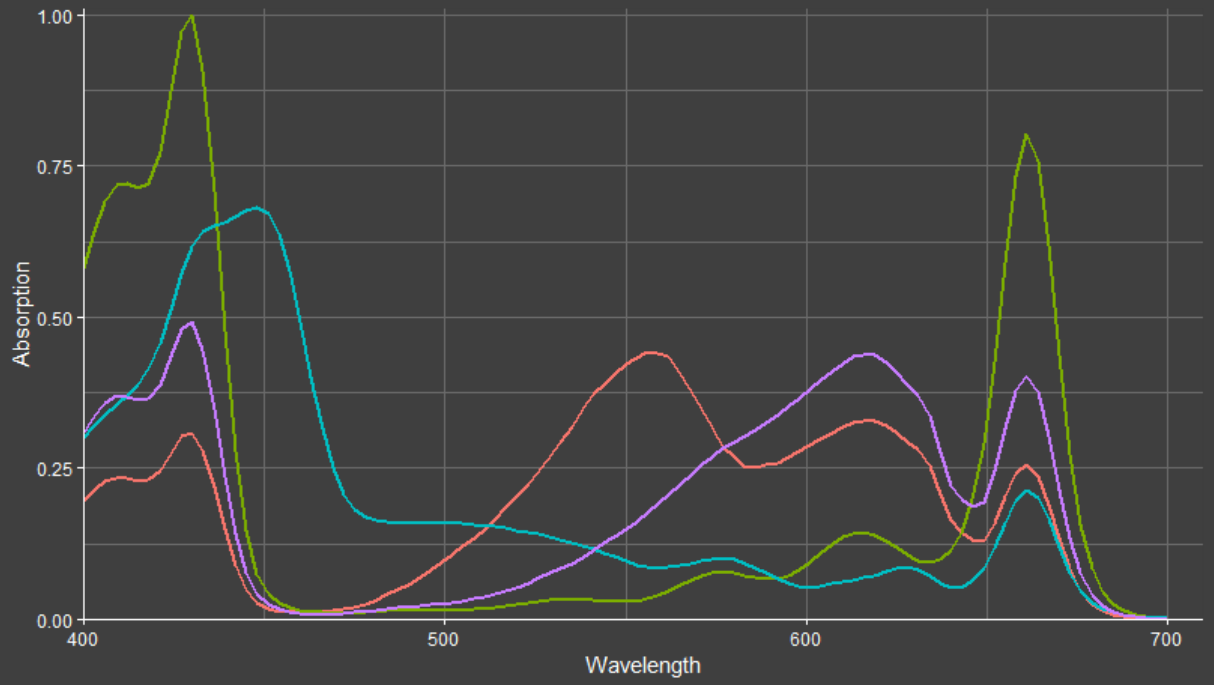
Model system: phytoplankton

Photoautotrophs: they need light

Important in carbon cycling

Reduce competition with differing pigmentation

Model system: phytoplankton



Different pigments allow absorption of different wavelengths of light

The model

Growth depends on **light absorption** and **photosynthetic efficiency φ**:

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$$\underbrace{\frac{\mathrm{d}N_i}{\mathrm{d}t}}_{\text{Growth rate}}$$

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The model

Growth depends on **light absorption** and **photosynthetic efficiency φ**:

$$\underbrace{\frac{\mathrm{d}N_i}{\mathrm{d}t}}_{\text{Growth rate}} \approx \underbrace{\gamma_i \varphi_i N_i}_{\text{Photosynthesis}} - \underbrace{L_i N_i}_{\text{Mortality}}$$

The model

Stressors act on the φ:

The model

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Stressed φ

The model

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$$\underbrace{\varphi_i}_{\text{Stressed } \varphi} = \underbrace{\varphi_{i,0}}_{\text{Base } \varphi}$$

The model

Stressors act on the φ:

$$\underbrace{\varphi_i}_{\text{Stressed } \varphi} = \underbrace{\varphi_{i,0}}_{\text{Base } \varphi} \prod_{l=0}^{s} \underbrace{(1 - e_{i,l})}_{\substack{\text{Individual} \\ \text{stressor effect}}}$$

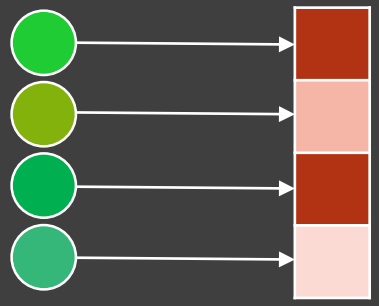
Generate four-species communities

Generate four-species communities

Control without stressor inclusion

Generate four-species communities

Generate stressor



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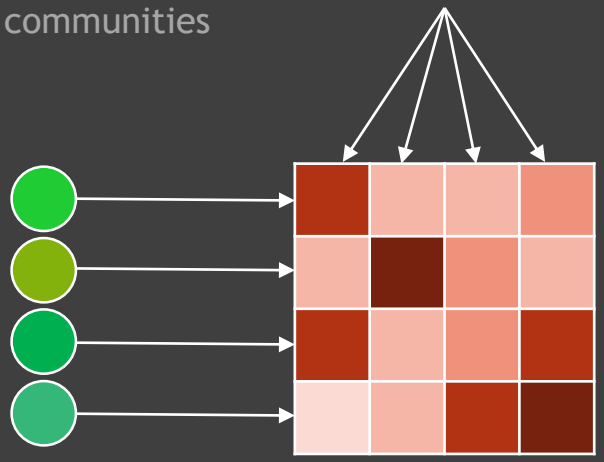
Generate stressors



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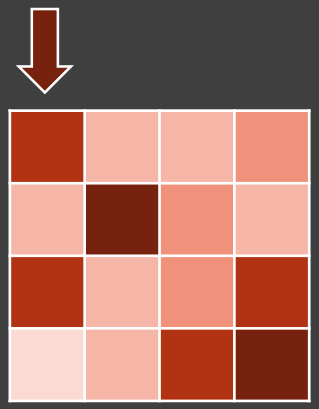
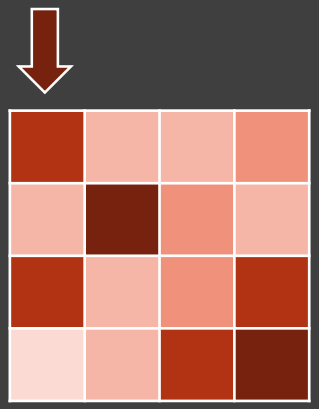


Apply stress to communities

Generate four-species communities

Generate stressors

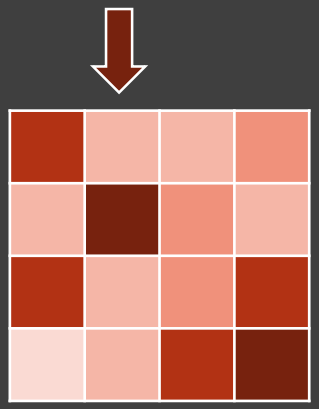


Apply stress to communities

Measure extinctions and community population

Generate four-species communities

Generate stressors



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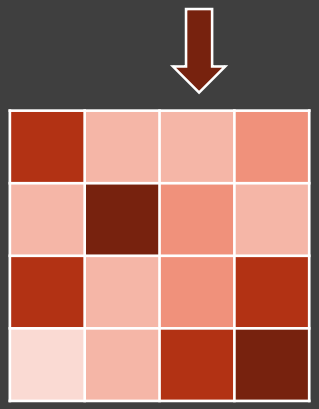

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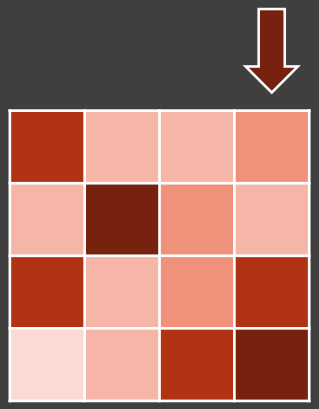

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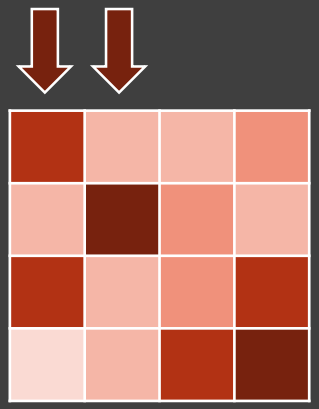

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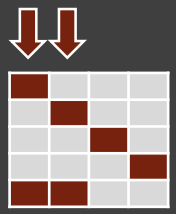

Measure extinctions and community population

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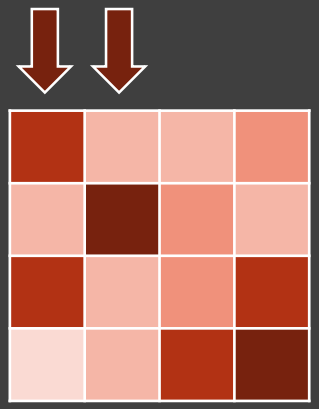
Generate stressors



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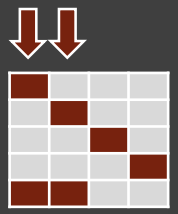
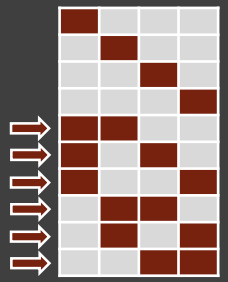


Measure extinctions and community population

Generate four-species communities

Generate stressors

Apply stress to communities

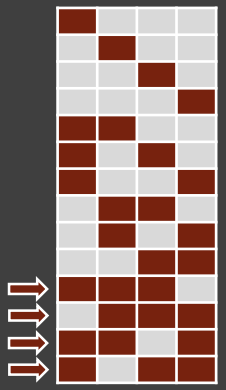


Measure extinctions and community population

Generate four-species communities

Generate stressors

Apply stress to communities

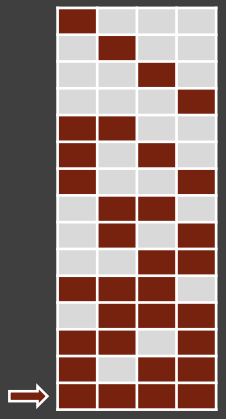


Measure extinctions and community population

Generate four-species communities

Generate stressors

Apply stress to communities



Measure extinctions and community population

Generate four-species communities

Generate stressors

Apply stress to communities

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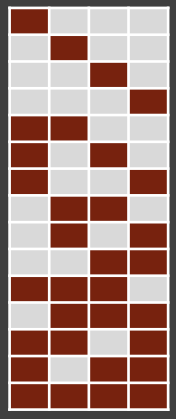


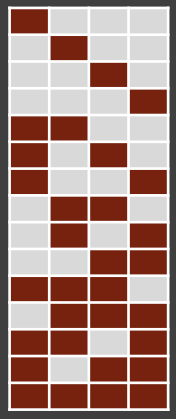
Stressors do not interact!

Generate four-species communities

Generate stressors

Apply stress to communities

Measure extinctions and community population



Stressors do not interact!

Stressor effect kept constant!

Interlude: keeping community impact constant

Stressor effect kept constant:

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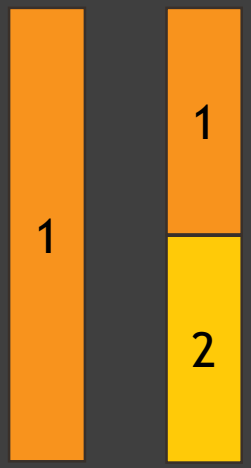

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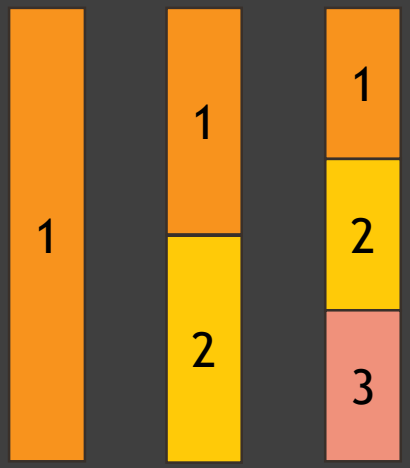

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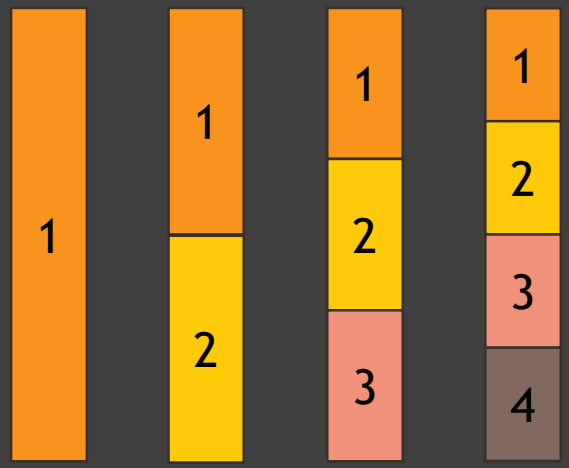

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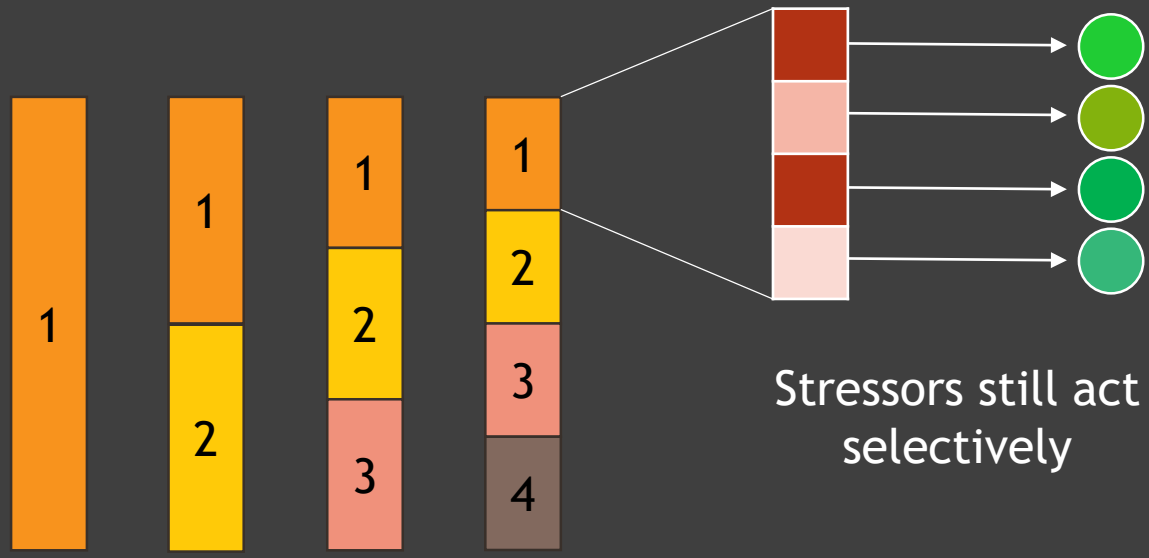

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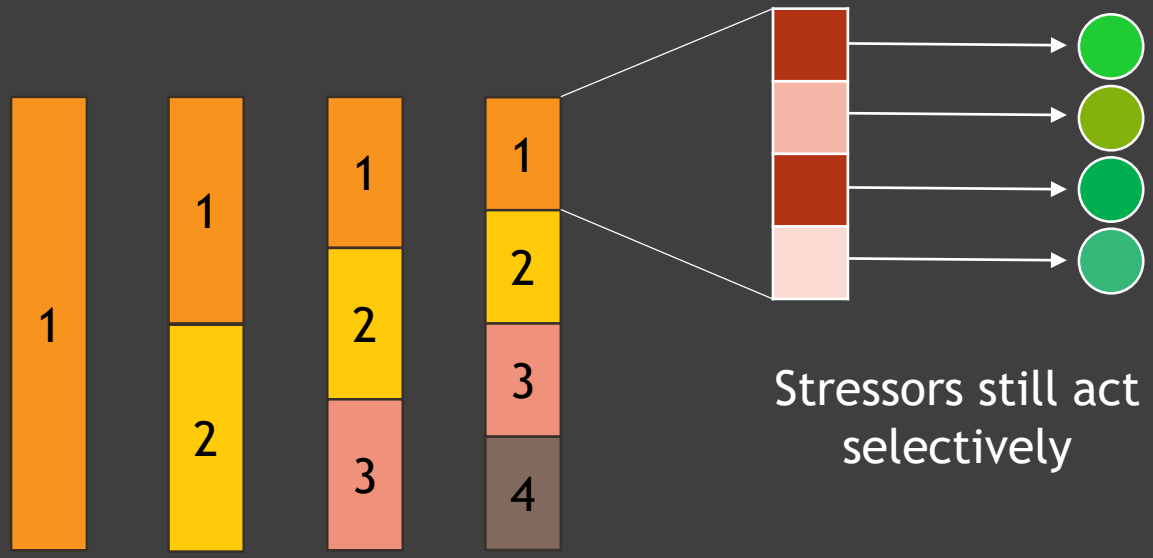
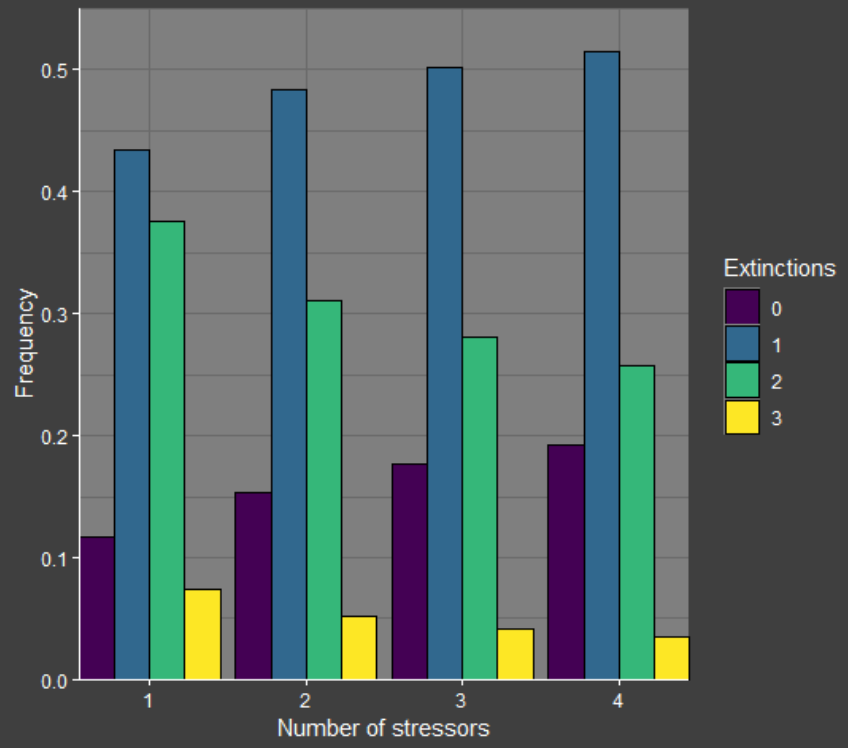


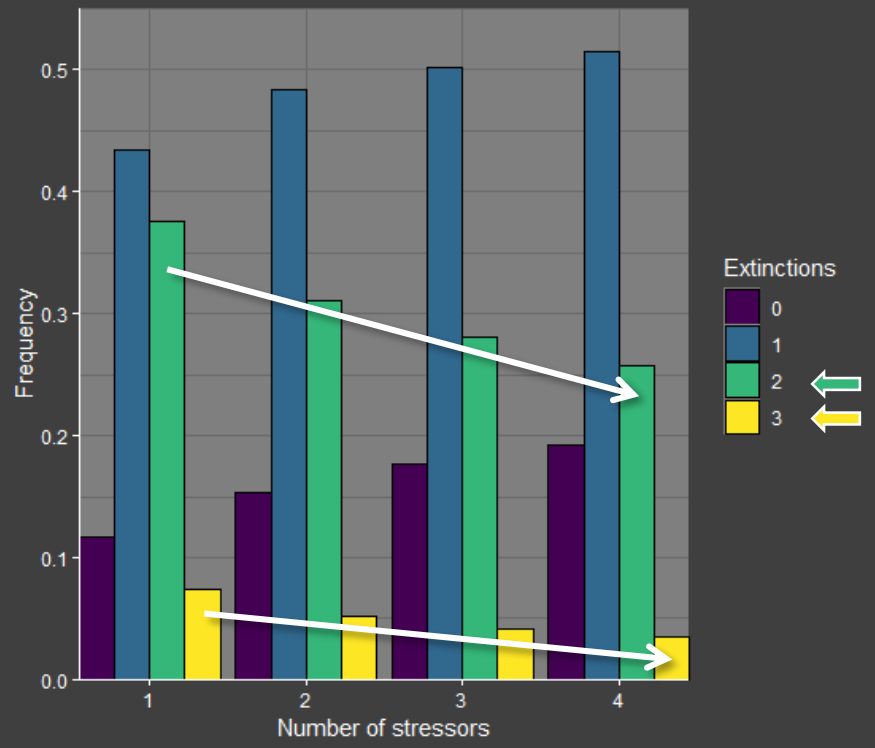
Impact on **the community** the same, regardless of number of stressors

More stressors: fewer extinctions



More stressors: fewer extinctions

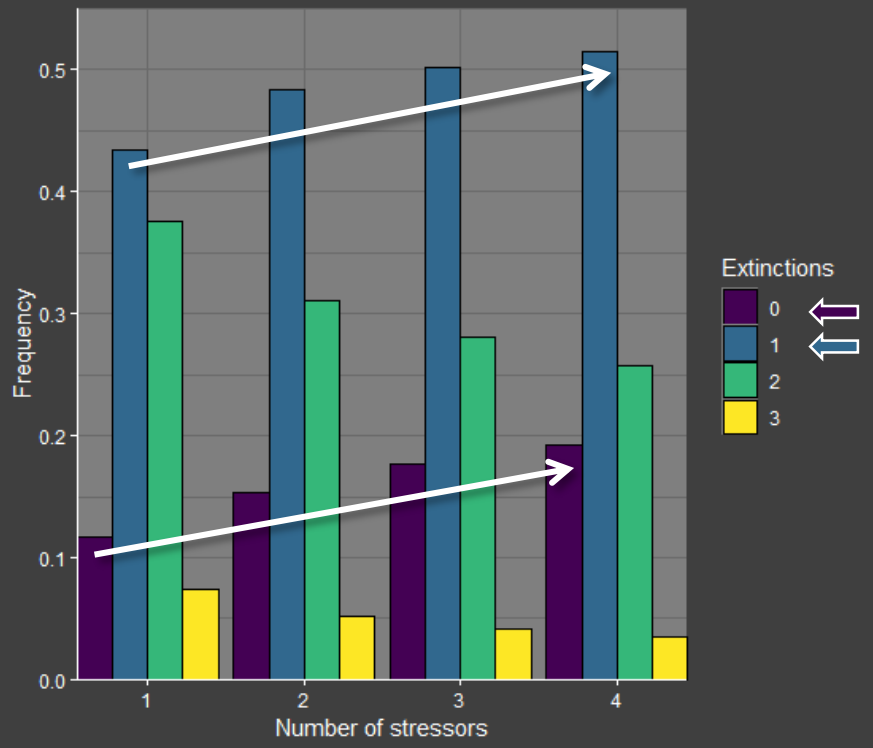
Fewer high-extinctions events



More stressors: fewer extinctions

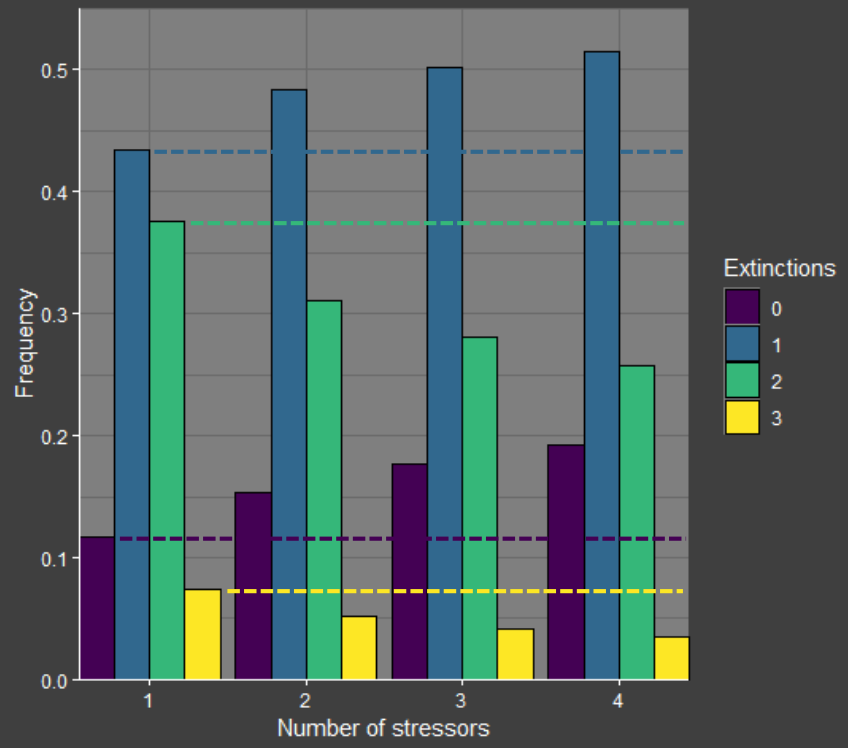
Fewer high-extinctions events

More low-extinction events



More stressors: fewer extinctions

- Fewer high-extinctions events
- More low-extinction events
- Additivity predicts constancy



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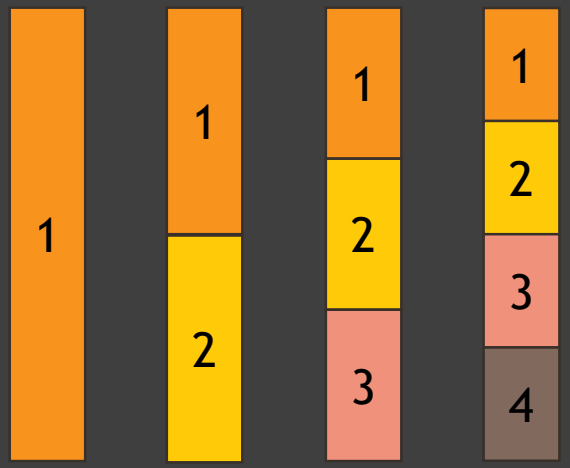
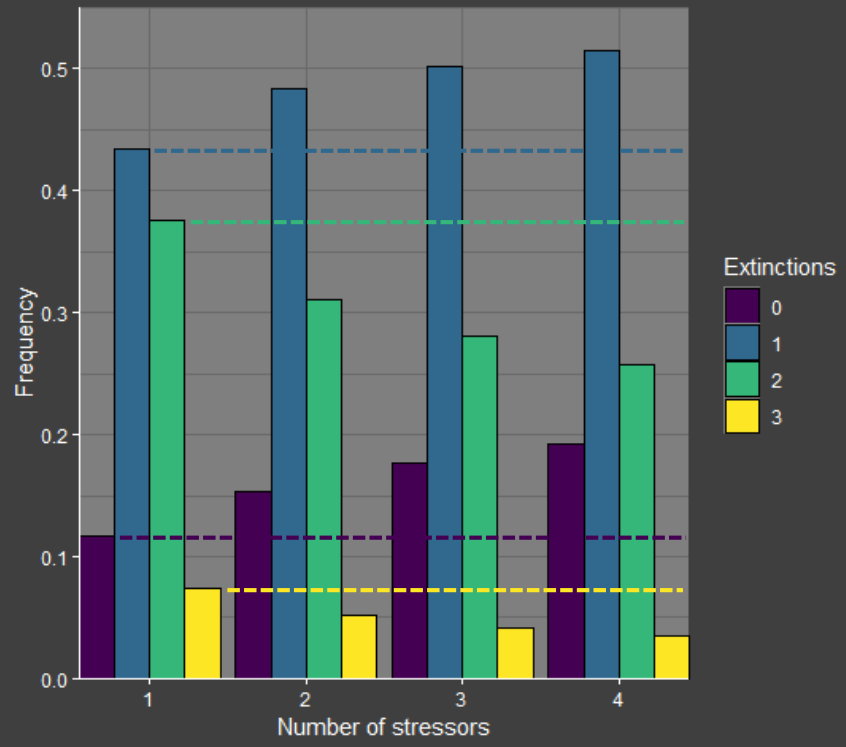
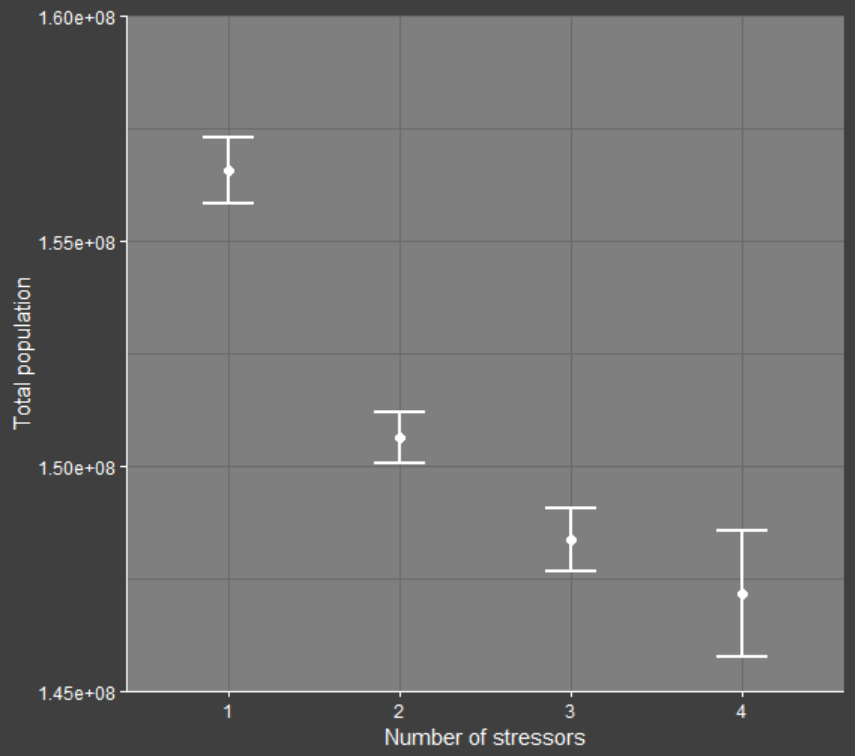




More stressors: lower productivity

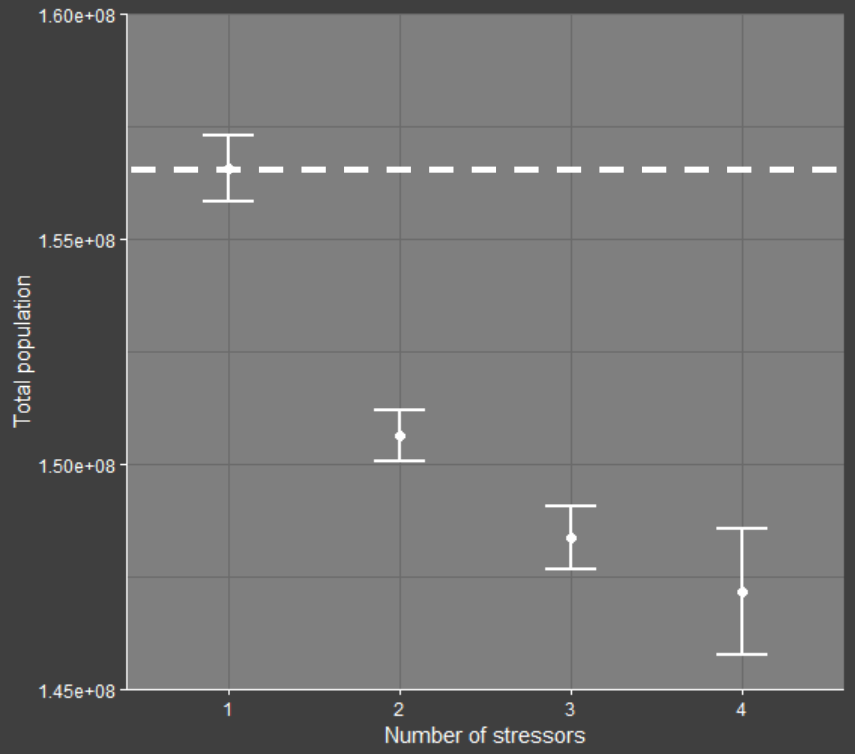
Total population density goes down

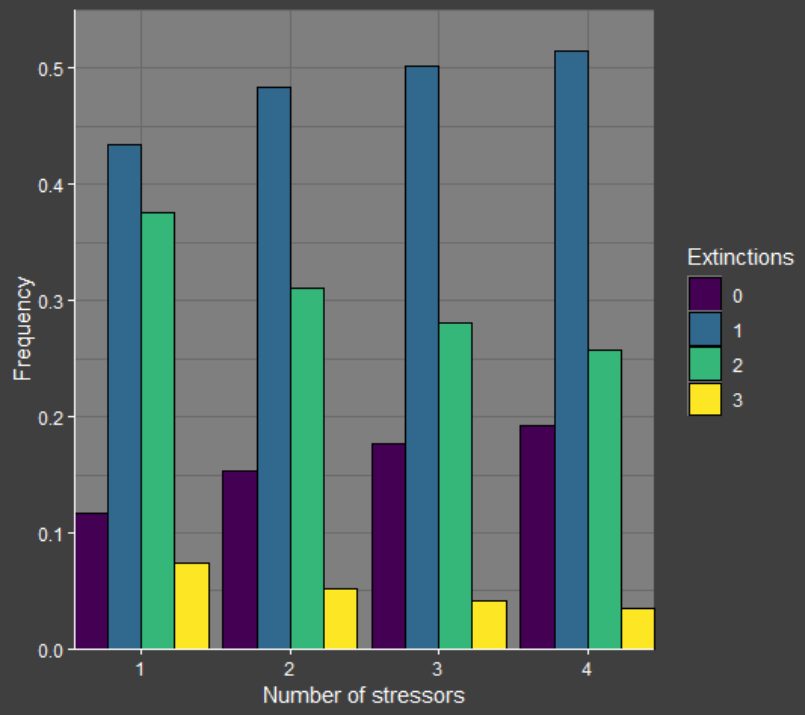


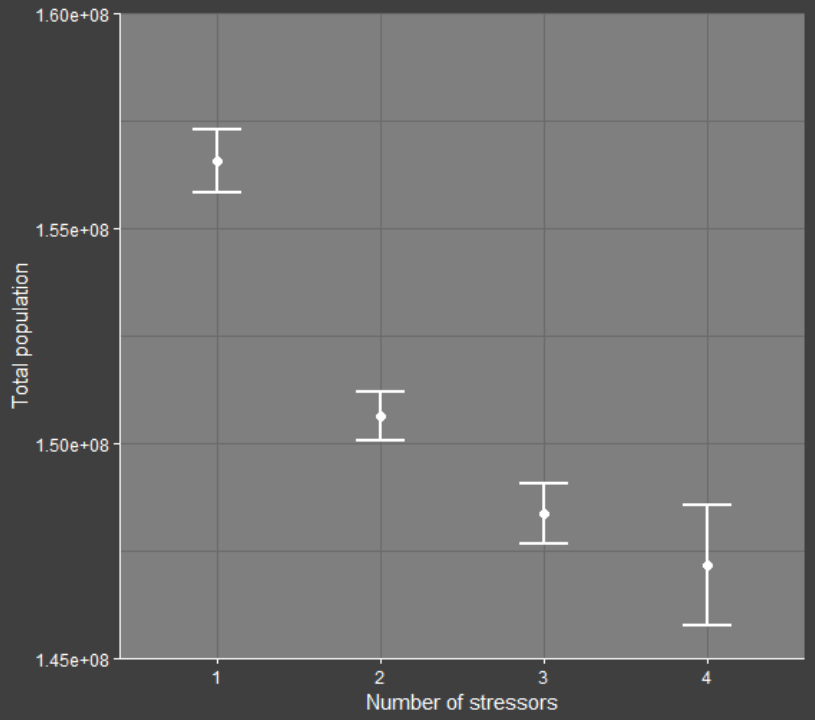
More stressors: lower productivity

Total population density goes down

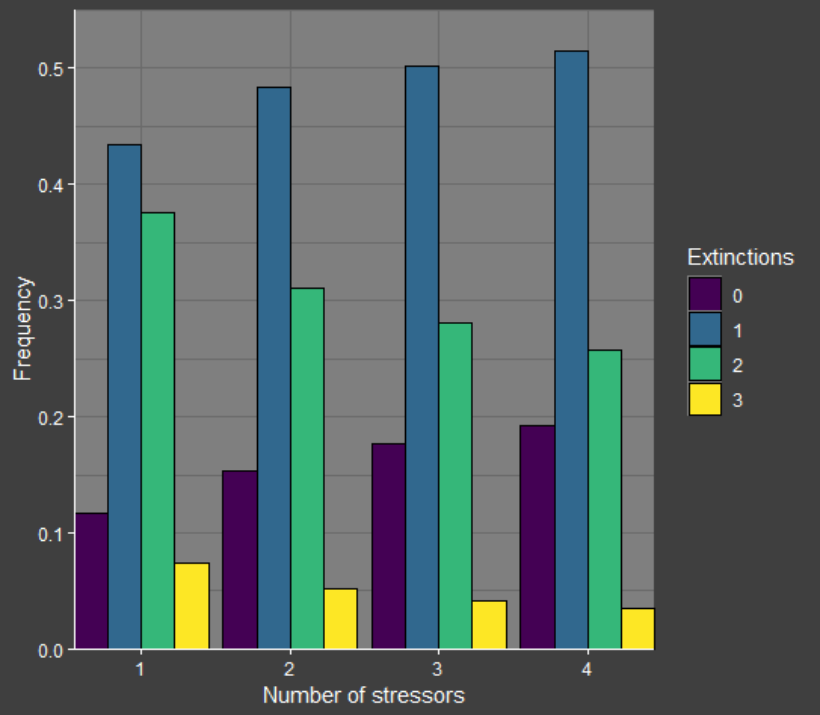
Additivity again predicts constancy

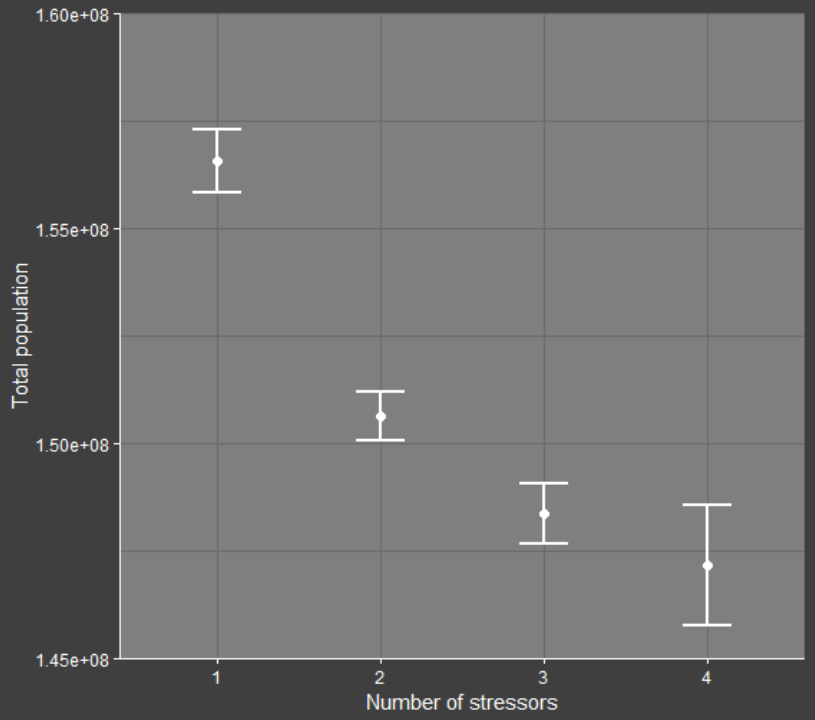


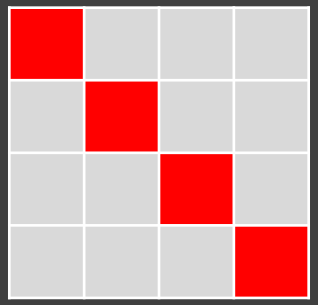




More stressors increase evenness of stressor effect across species


Frequency
0.0
0.1
0.2
0.3
0.4
0.5
1
2
3
4
Number of stressors
Extinctions
0
1
2
3


Total population
1.45e+08
1.50e+08
1.55e+08
1.60e+08
1
2
3
4
Number of stressors



What did we learn?

Does the total number of stressors matter?

YES! Stressor number matters, even when keeping community effect constant

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Can non-additivity occur without stressor interactions?

YES!

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YES! Stressor number matters, even when keeping community effect constant

Can non-additivity occur without stressor interactions?

YES!

Are interactions so important?

STILL TO DO

What's next?

Stressor interactions!

Experiments!

Thanks for your attention!

Equations in full

Light absorption:

$$\gamma_i(z) = \int_{400}^{700} I(\lambda, z) k_i(\lambda) \mathrm{d}\lambda$$

Growth dynamics:

$$\frac{\mathrm{d}N_i}{\mathrm{d}t} = \frac{\varphi_i}{z_m} \int_0^{z_m} \gamma_i(z) N_i \mathrm{d}z - L_i N_i$$

Stressor standardisation:

$$product_{out} = product_{init}^{\frac{\ln(product_{des})}{\ln(product_{init})}}$$