Mechanisms of the Emergence of Extreme Harmful Algal Blooms

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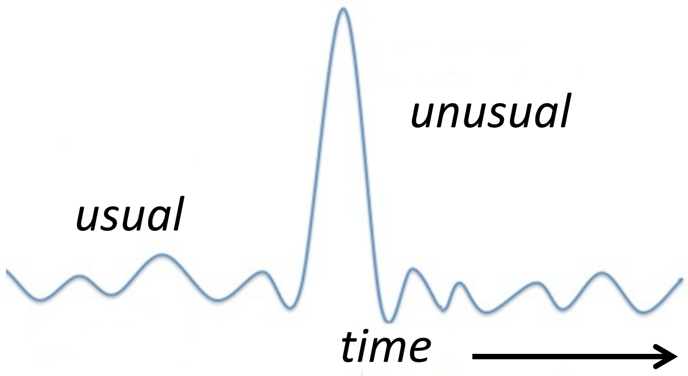
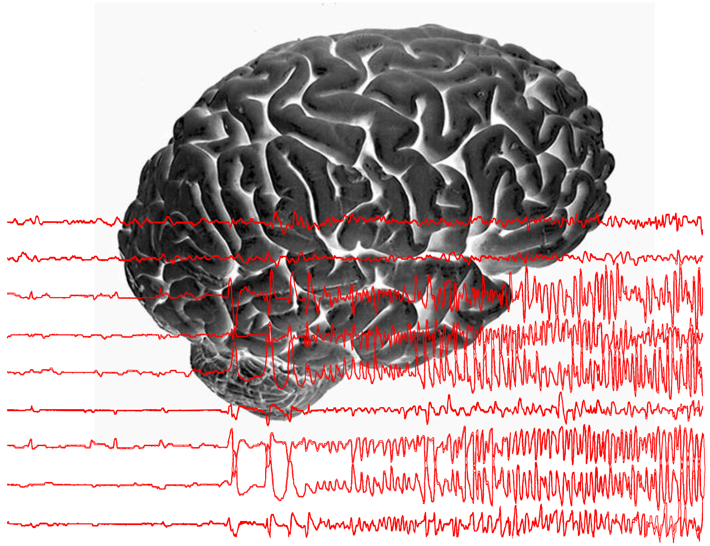
Extreme events



extreme event (ExEv): rare but recurrent events characterized by a large impact on a particular system

typical examples:

excitable systems

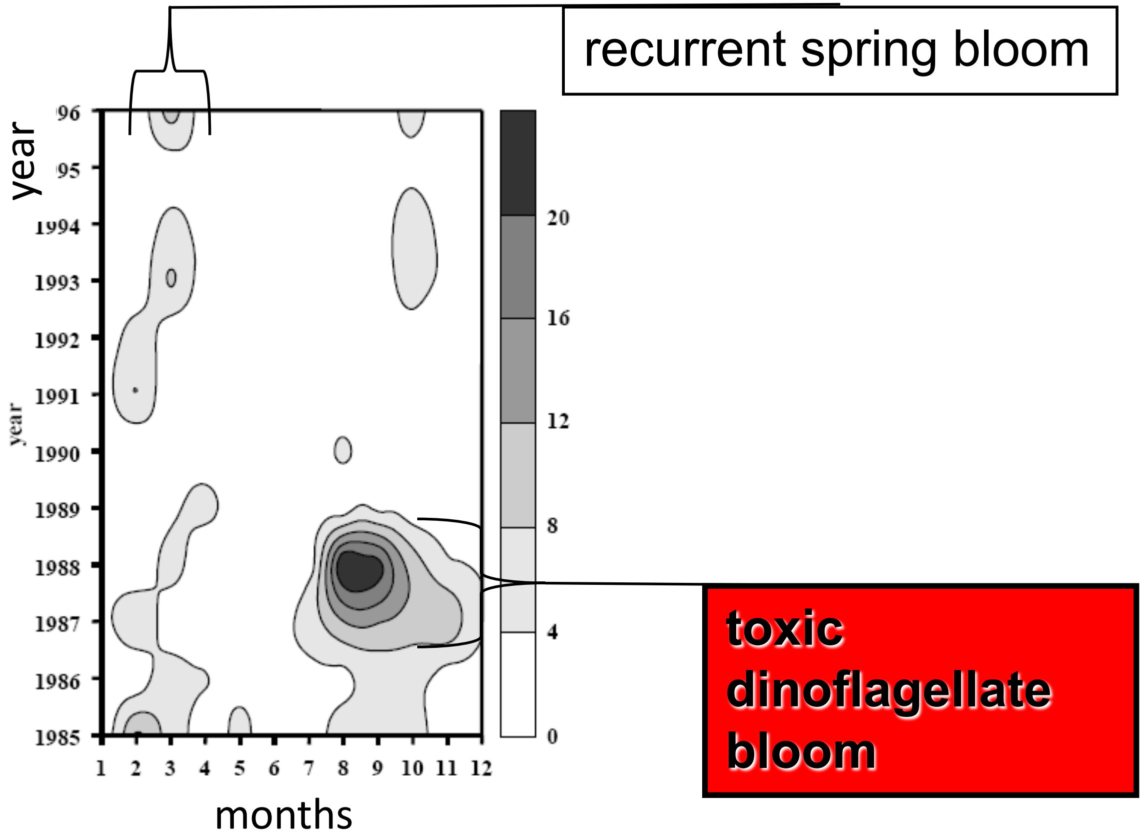


Harmful Algal Bloom (HAB)

Epileptic Seizures (ES)

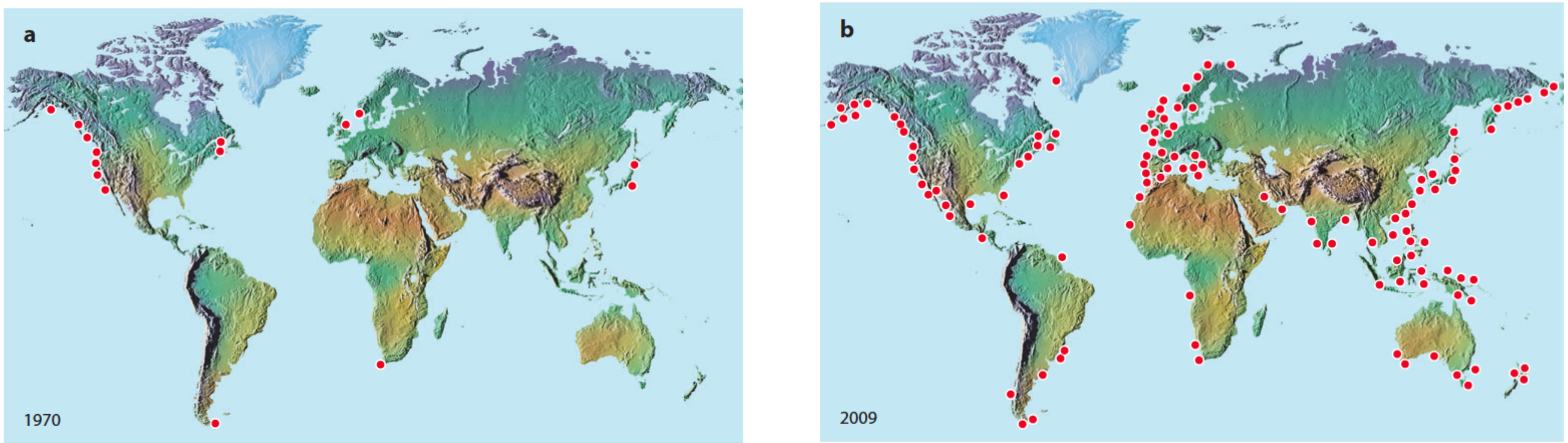
Harmful algal blooms (HABs)

HAB: Large abundance of a potentially toxic plankton species



Gullmar Fjord in the Skagerrak.
[Belgrano et al. 1999 Proc. R. Soc. London B]

Harmful algal blooms and climate change



[Anderson et al., 2012]

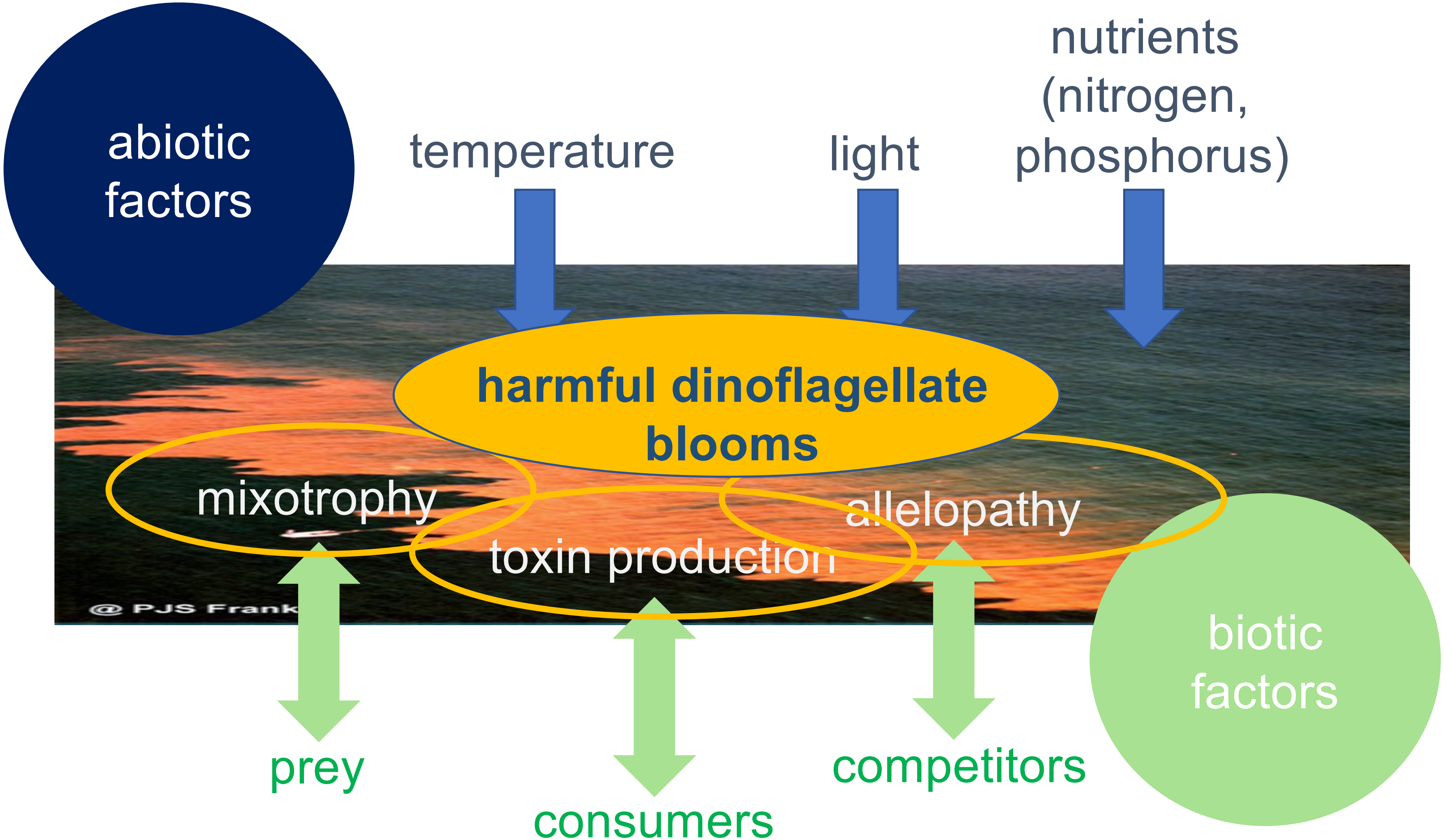
Increase in the number of events

Possible causes:

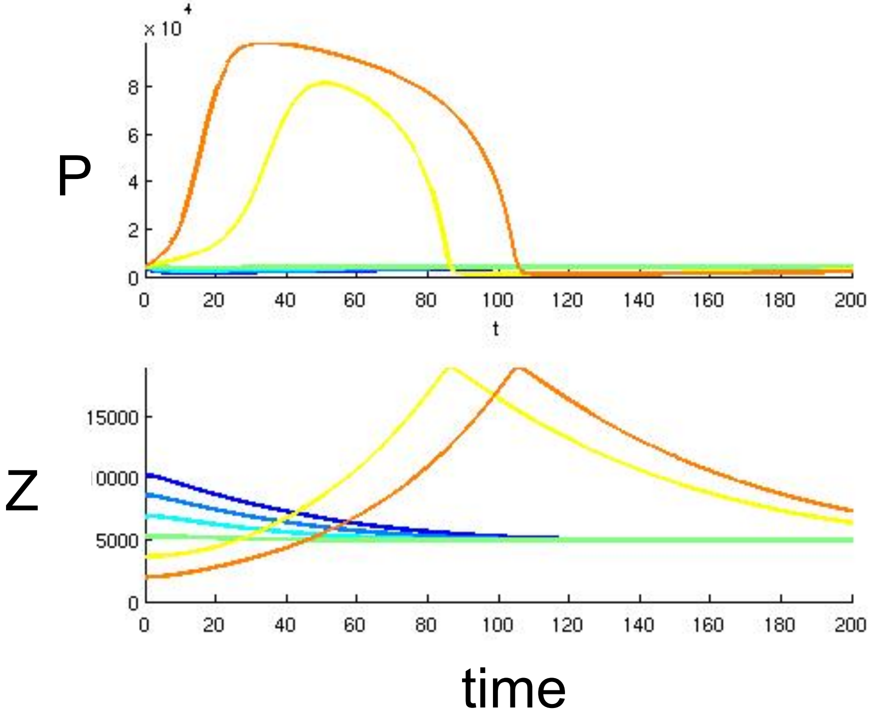
- Eutrophication: increase of nutrient input
- Warming oceans
- Invasion of new species
- Changes in wind patterns

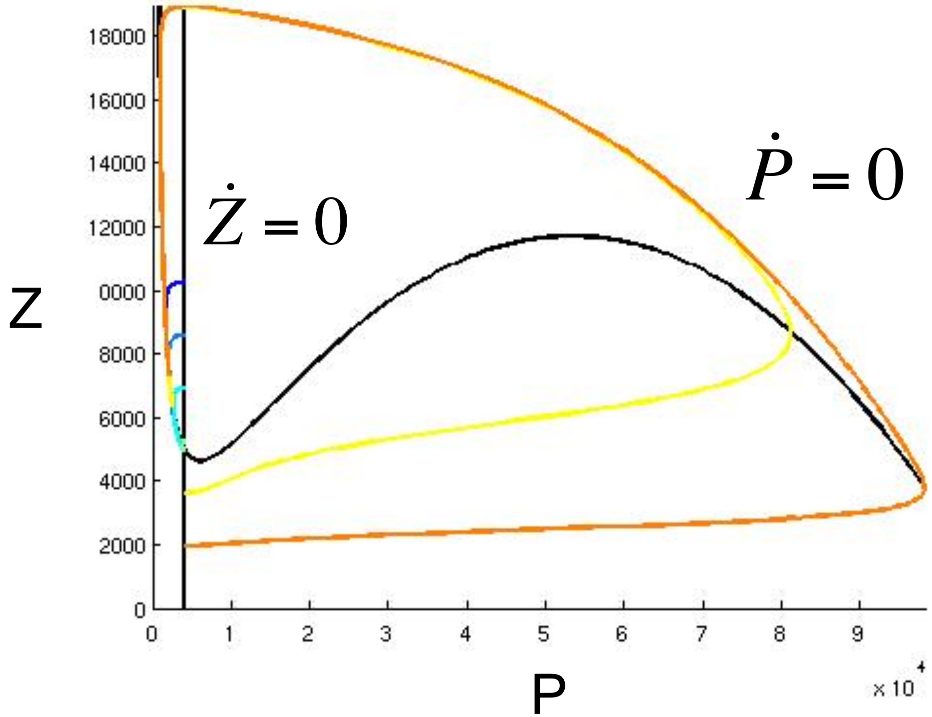
➡ Study of trigger mechanisms of HABs are necessary

Important factors influencing HABs



Dynamics of the excitable plankton model

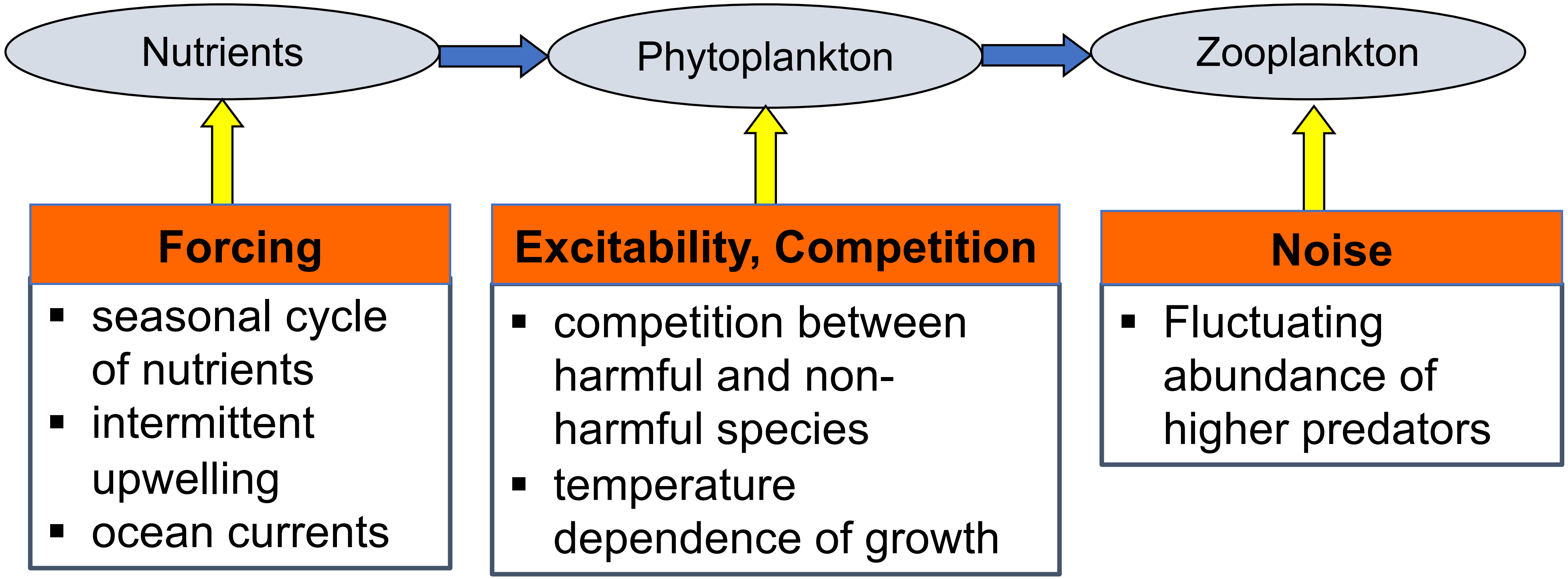




Plankton bloom is only triggered for particular initial conditions, when zooplankton has a low initial abundance

To model HABs: Include nutrients, preference of zooplankton, competition between toxic/non-toxic species

Modeling of plankton blooms



Nutrients: dN/dt = upwelling – uptake + recycling

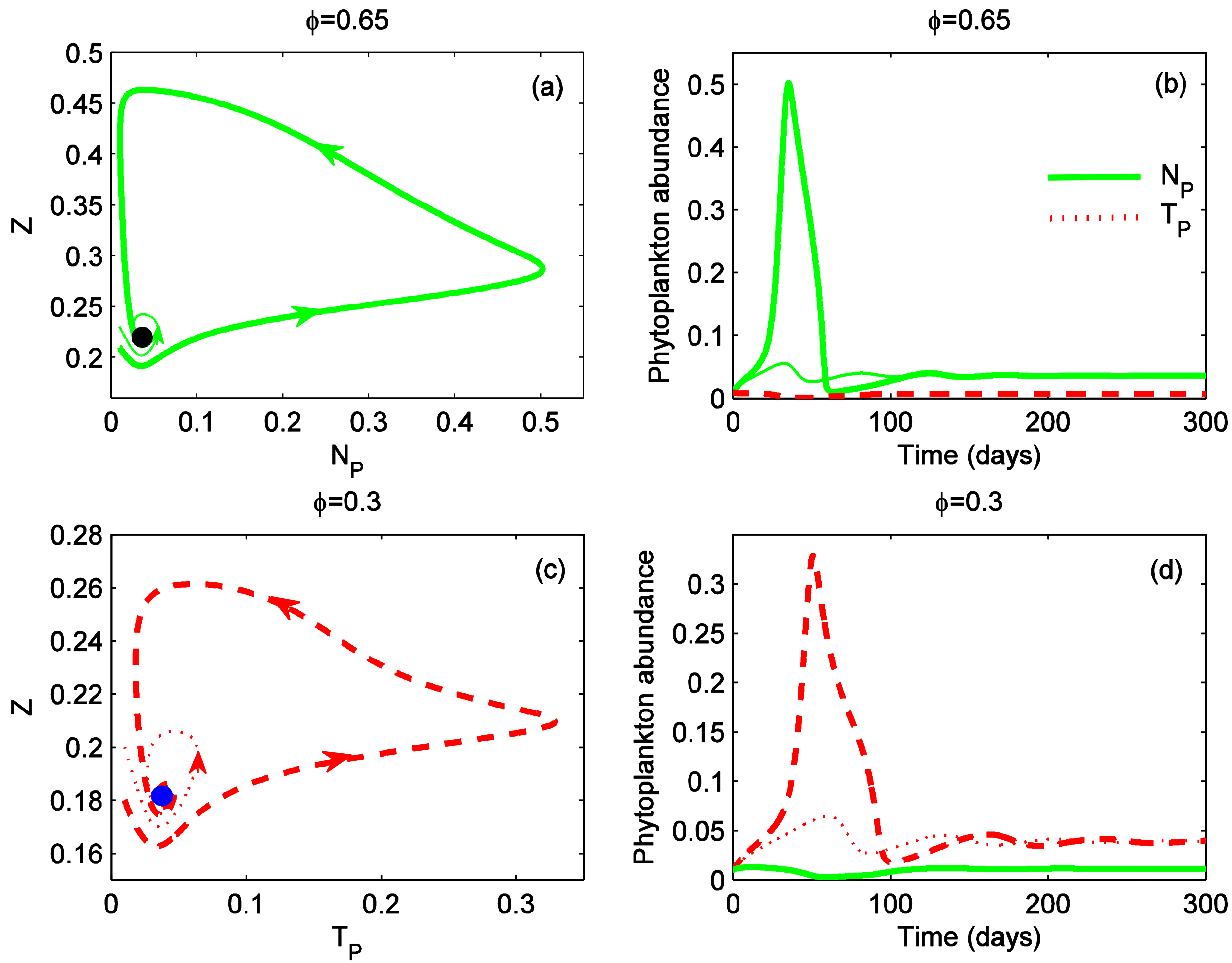
Phytoplankton: dP/dt = uptake – grazing – mortality - sinking

Zooplankton: dZ/dt = growth – mortality

Impact of selective feeding

High preference of harmful species

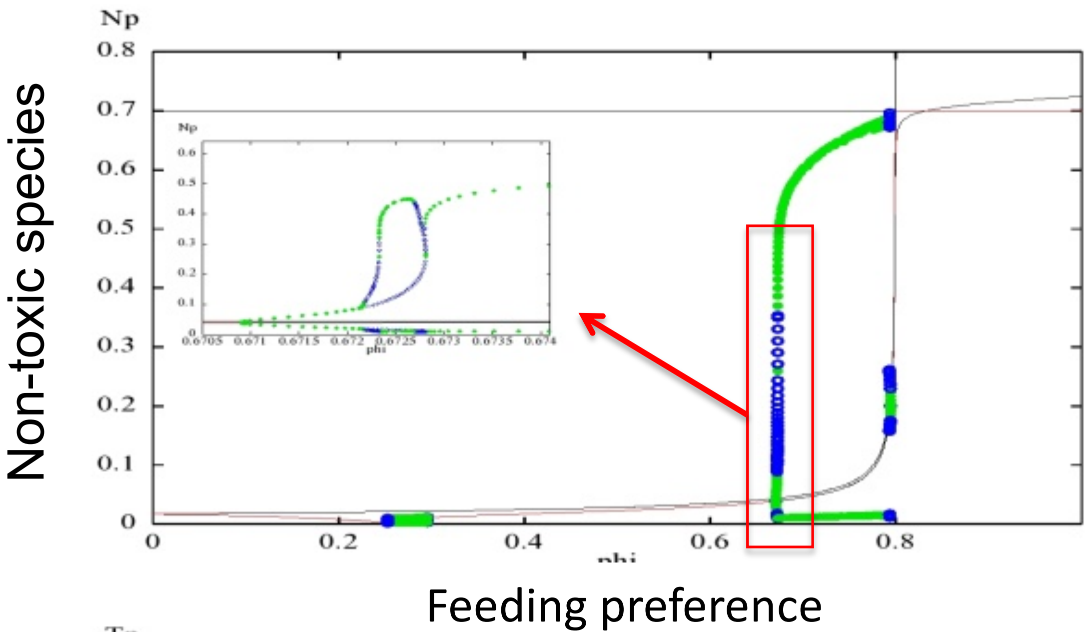
Low preference of harmful species

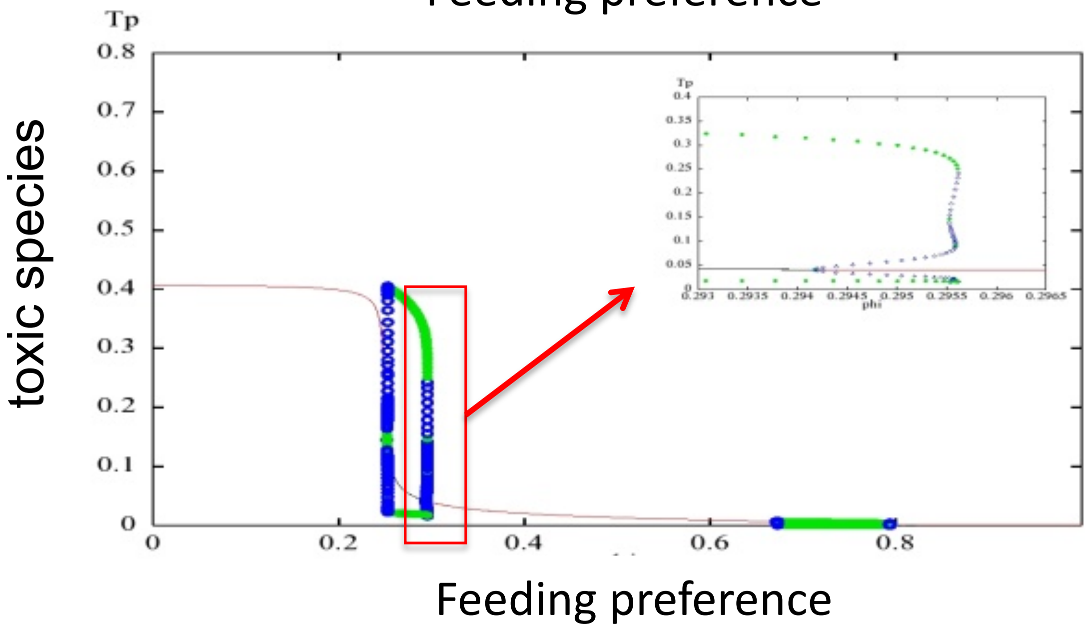


➡ Even with inclusion of the dynamics of nutrients the dynamics is excitable – but in a different way

Excitability of second kind

Exists in the neighborhood of subcritical Hopf bifurcations

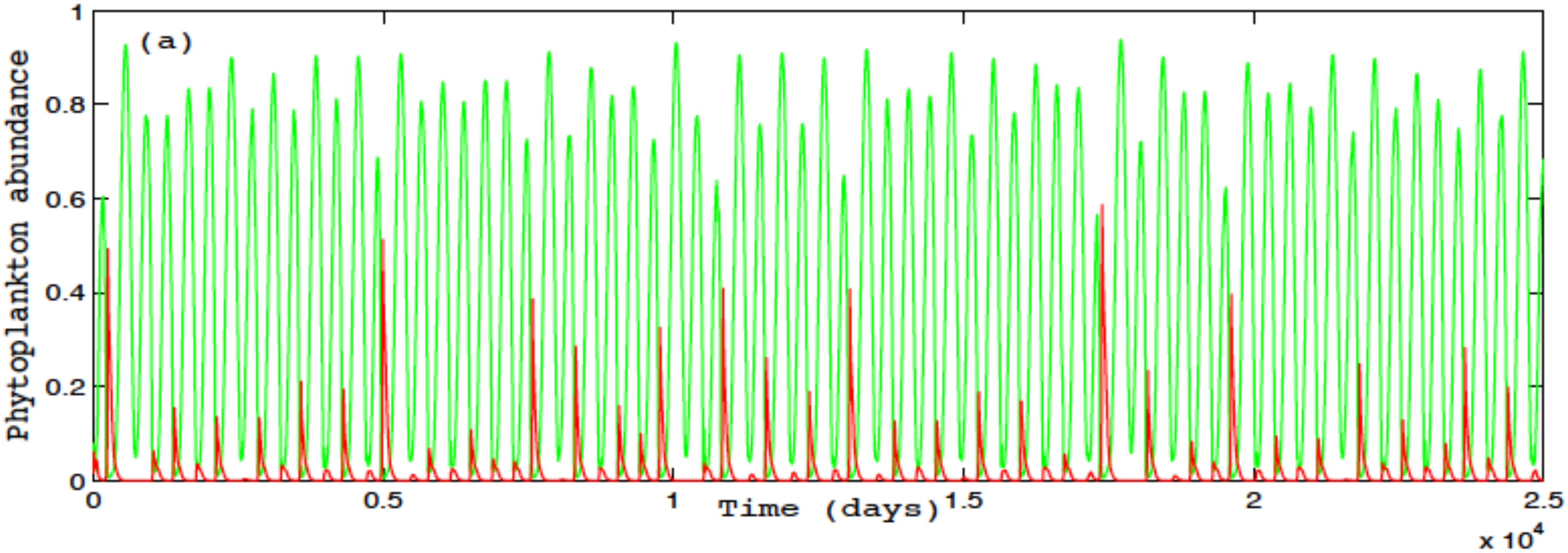




Combining periodic nutrient input and noise

Nutrient input changes with the seasonal cycle due to changes in vertical mixing *[K. Wiltshire et al., 2010]* : $N_0(t)=N_0 \cos(2\pi t/365)$

Zooplankton mortality changes on a daily basis *[Beninca et al. 2011]* :
Mortality rate $d(t) = d + \eta_t$; η_t – white Gaussian noise



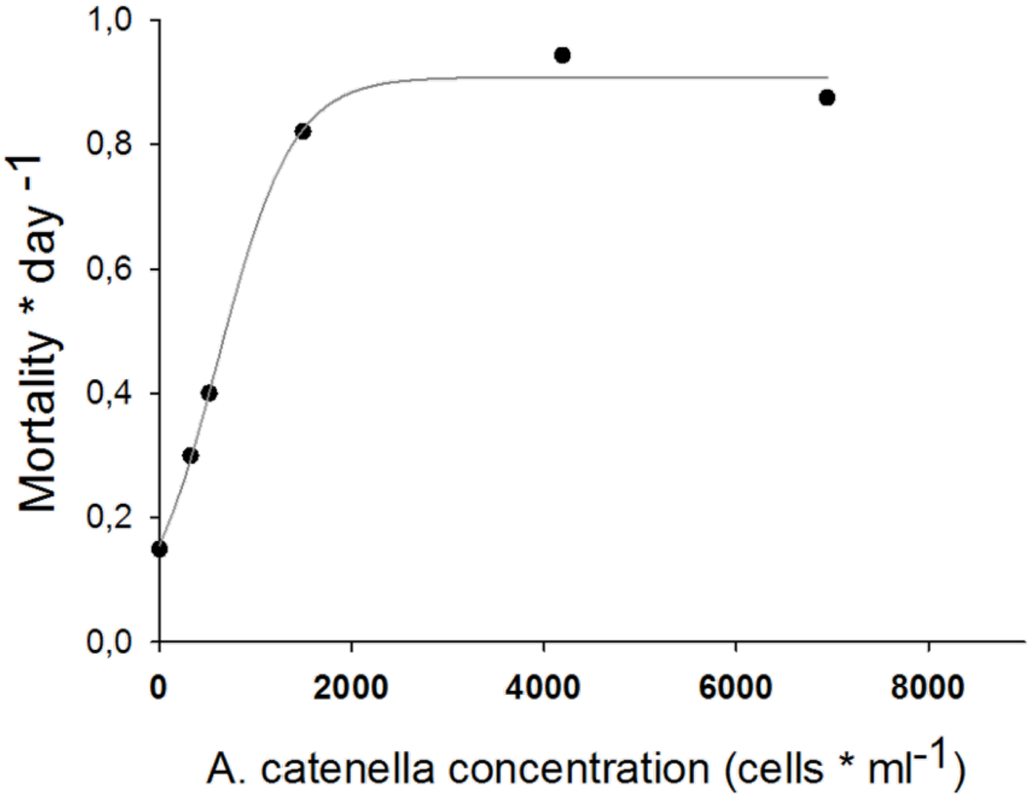
→ **occasional harmful algal blooms**

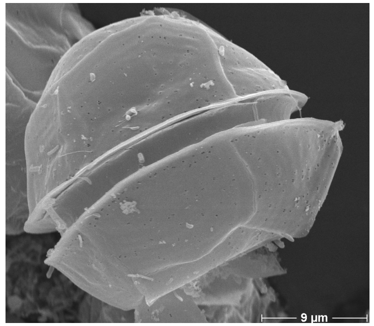
→ **top-down control is important the mechanism**

[S. Chakraborty, U. Feudel (2014), *Harmful algal blooms: combining excitability and competition*. Theor. Ecol. 7, 221-237]

Toxin experiments

Toxic effects of *Alexandrium* on zooplankton grazers:





Toxic algae:
Alexandrium catenella

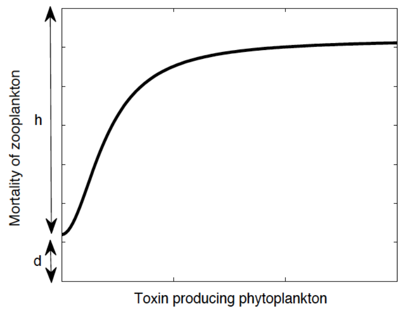
Rotifer grazer
Brachionus plicatilis

→ **significant increase of zooplankton mortality with increasing algal cell concentrations**

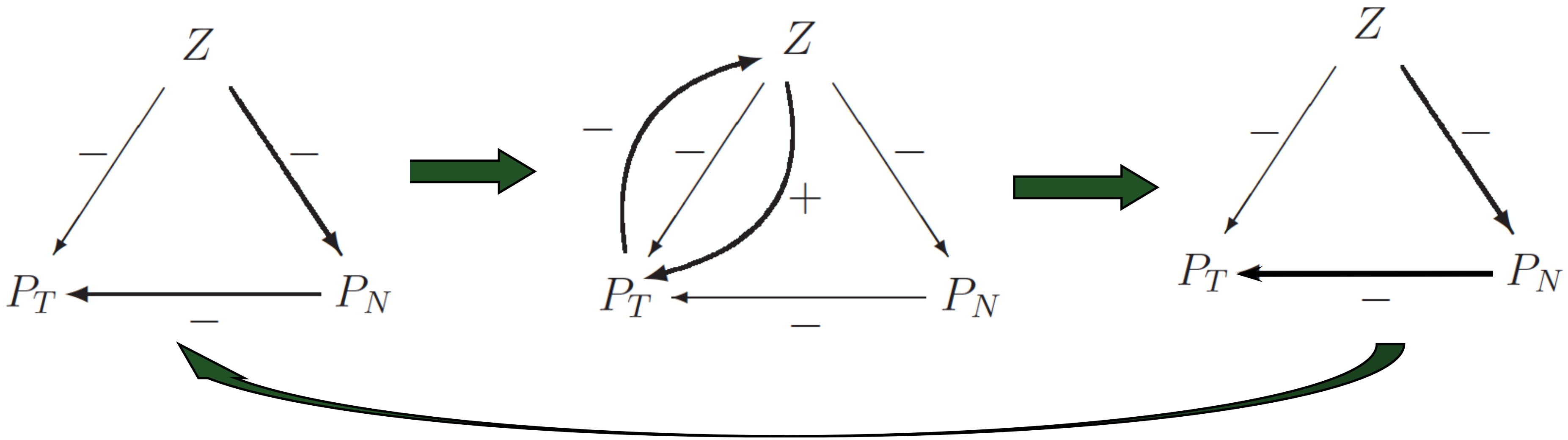
[M. Busch et al. in preparation.]

Additional feedback between harmful species on the grazer: toxin kills predator

Experiment:



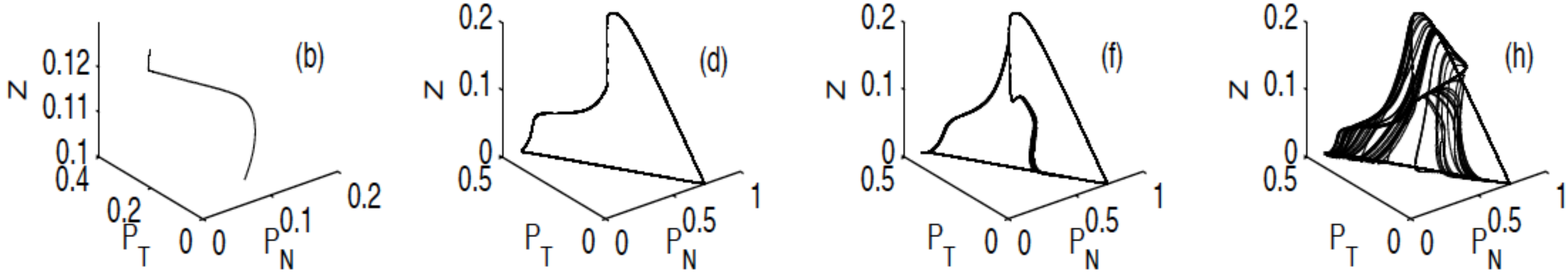
Cost for toxin production → lower growth rate as the non-toxic competitor

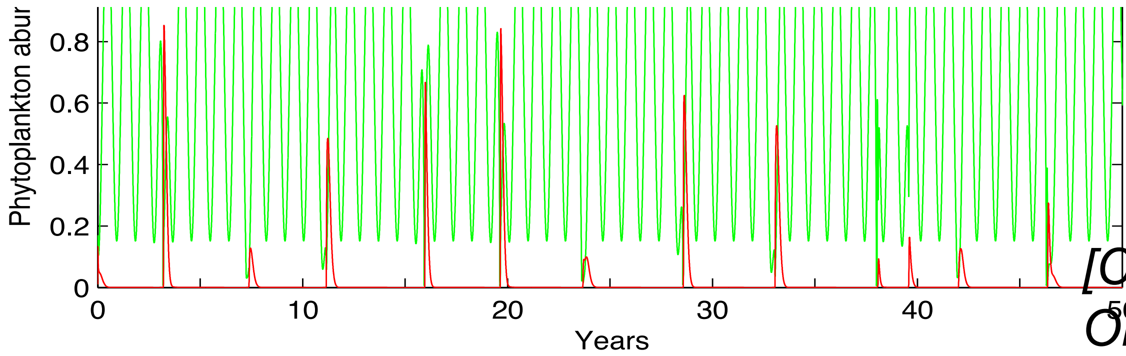


Strong direct toxic effect (negative feedback) is not beneficial → killing the grazer by toxins leads to an advantage for the non-toxic species, who in turn suppresses the toxic one

Toxin production induces HAB irregularity

Increasing toxicity →



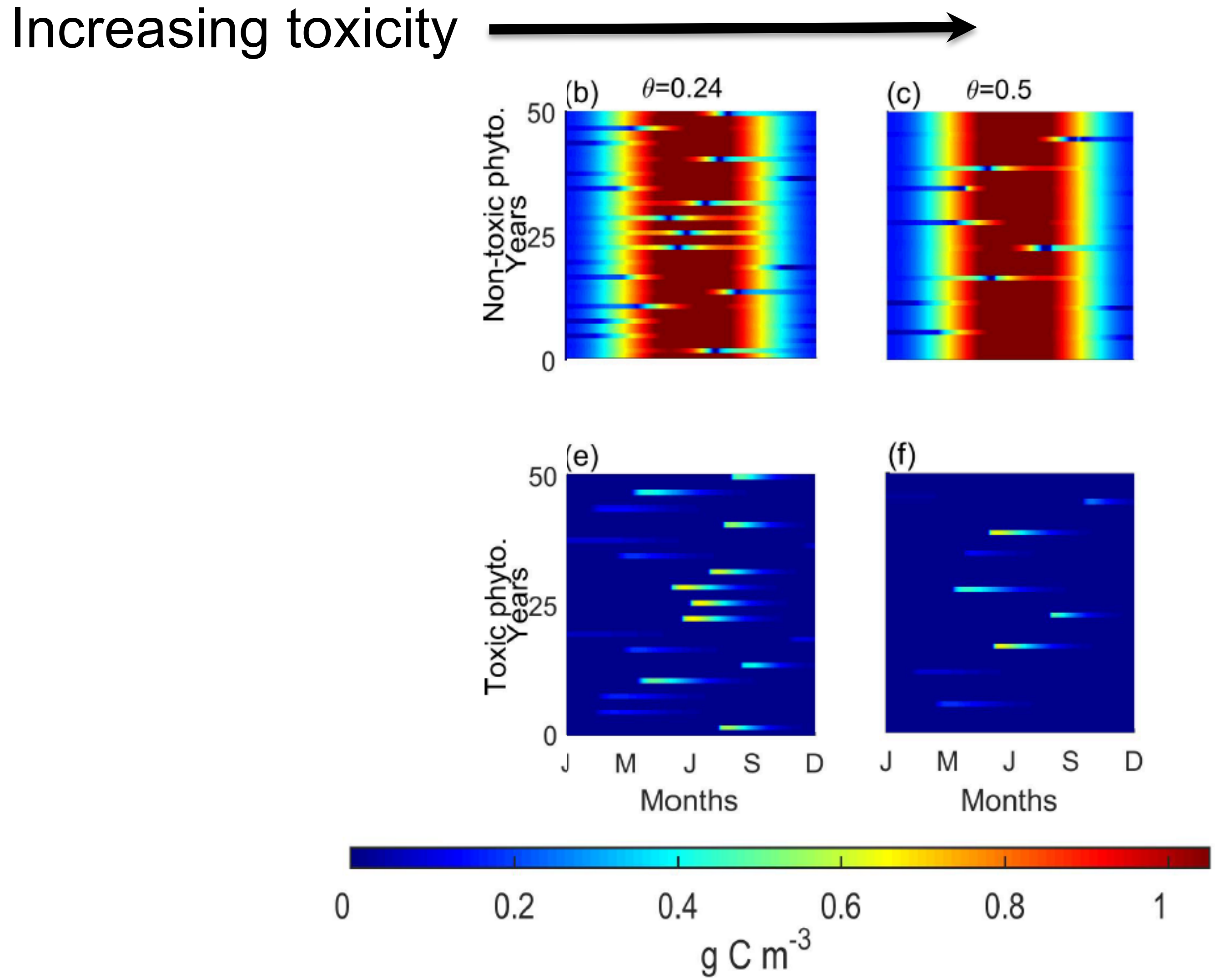


[Chakraborty et al., Oikos, submitted]

- Irregularity of harmful algal blooms is induced by the direct toxic effect
- Strong direct toxic effect is not beneficial → killing the grazer by toxins leads to an advantage for the competitor

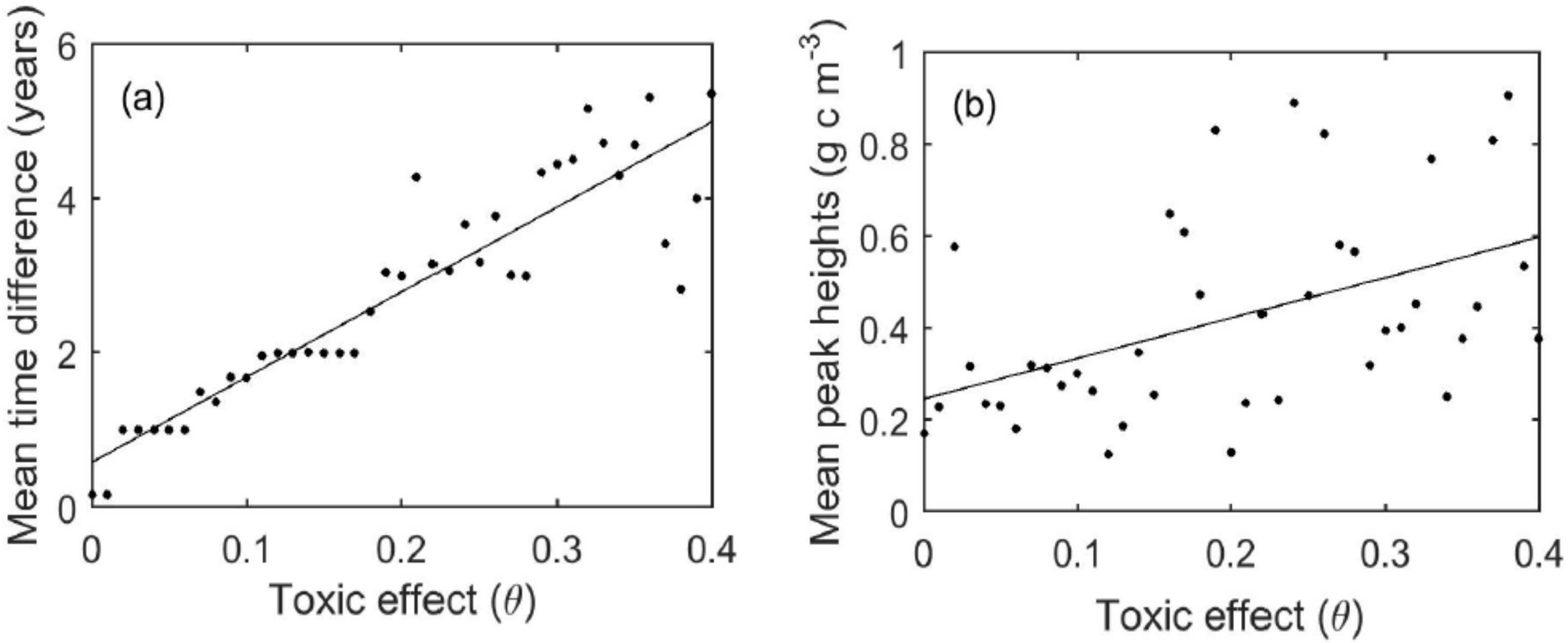
Consequences of toxins for the dynamics I

Increasing toxicity



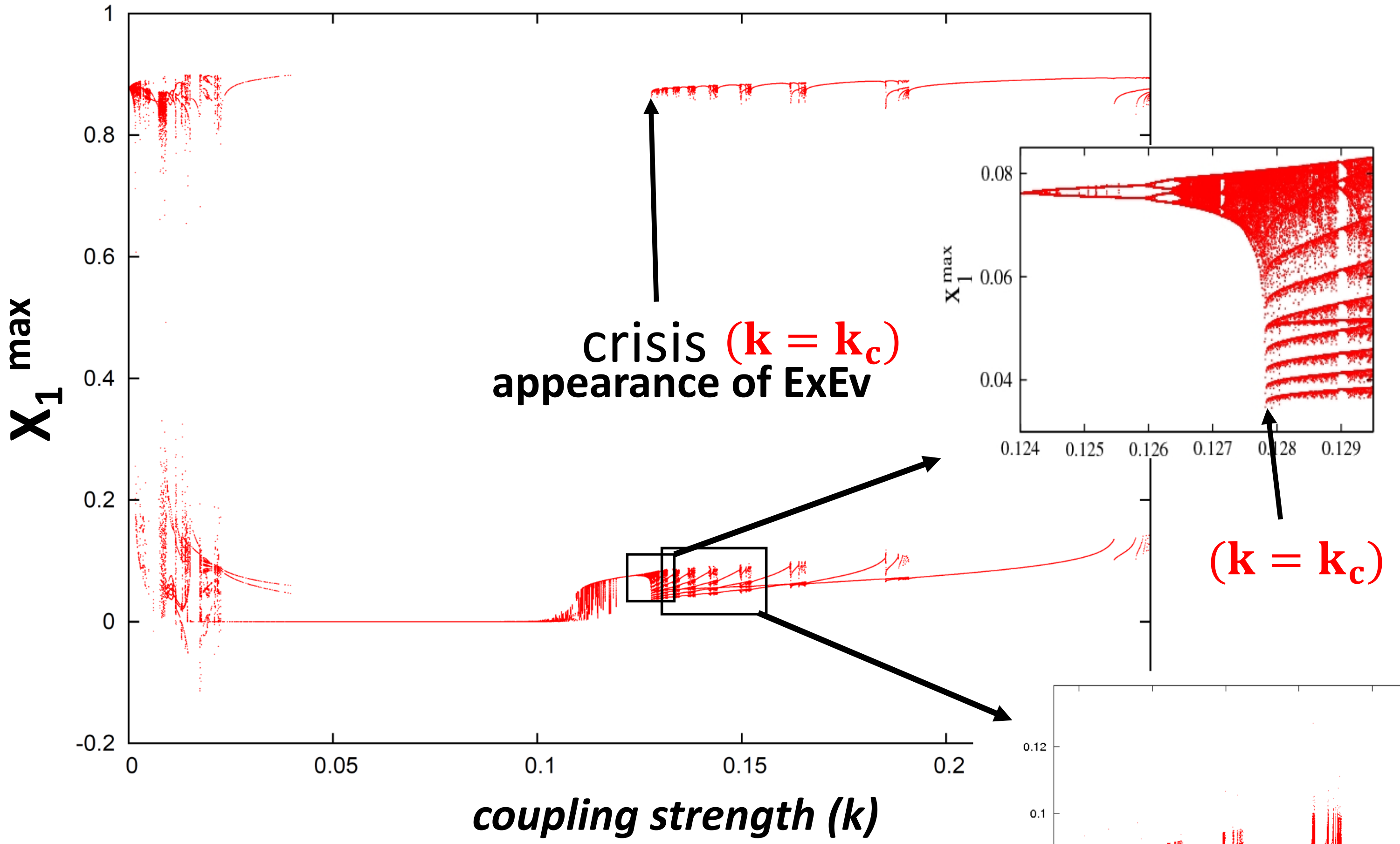
Toxic blooms become less frequent with increasing toxicity

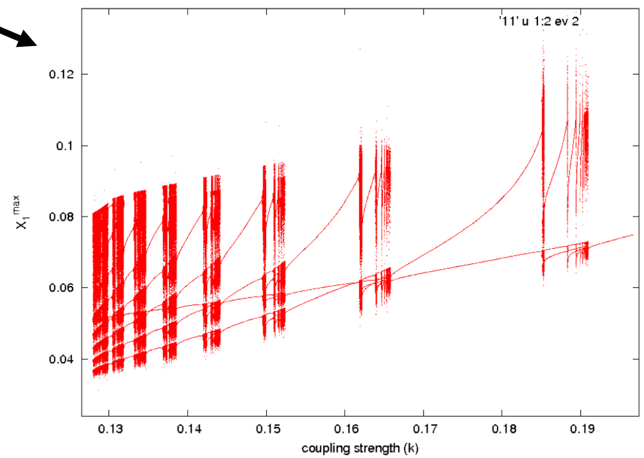
Consequences of toxins for the dynamics II



Increasing toxic effect makes toxic blooms rarer and more severe

Analogy to another model exhibiting extreme events: coupled FHN oscillators

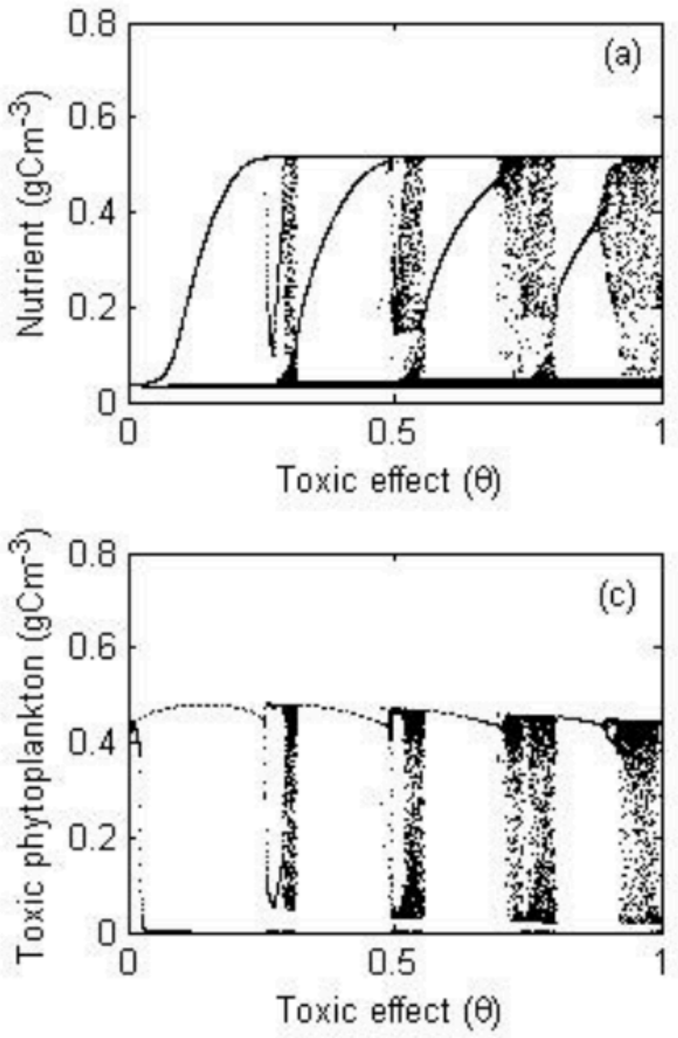


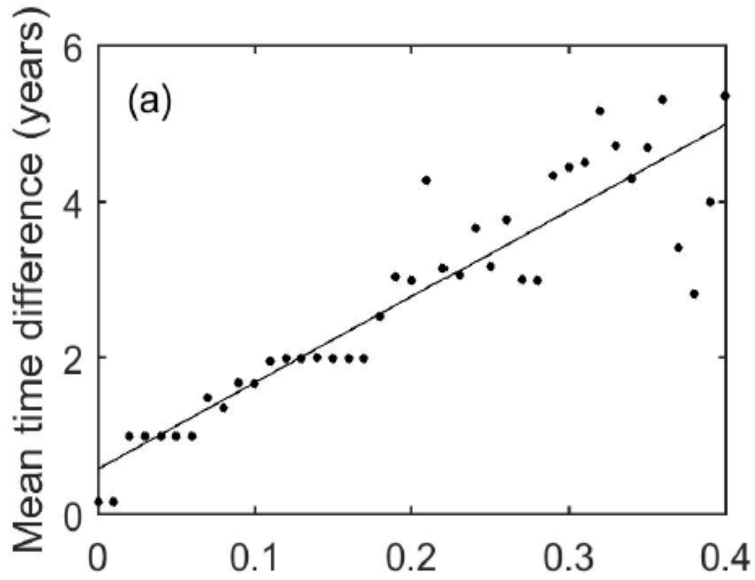


- Extreme events occur at a crisis where period doubling and period adding cascades meet
- The closer the crisis, the rarer are the events

Comparison to the HAB model

Increasing toxicity →





→ Increasing toxicity means approaching the crisis → longer tiem intervals between extreme events

Conclusions

- HABs can be modelled based on ideas of excitable systems known from neurodynamics
- competition between different species + seasonal cycle of nutrients + stochastic zooplankton → qualitatively correct dynamics
- Incorporating the impact of toxicity on the growth of the grazers → rare blooms even in a deterministic setting
- The larger the toxicity, the rarer and more severe are the HABs
- Dynamics of this specific model shares many properties with paradigmatic models exhibiting the emergence of extreme events