Multistability of model and real dryland ecosystems through spatial self-organization

Robbin Bastiaansen

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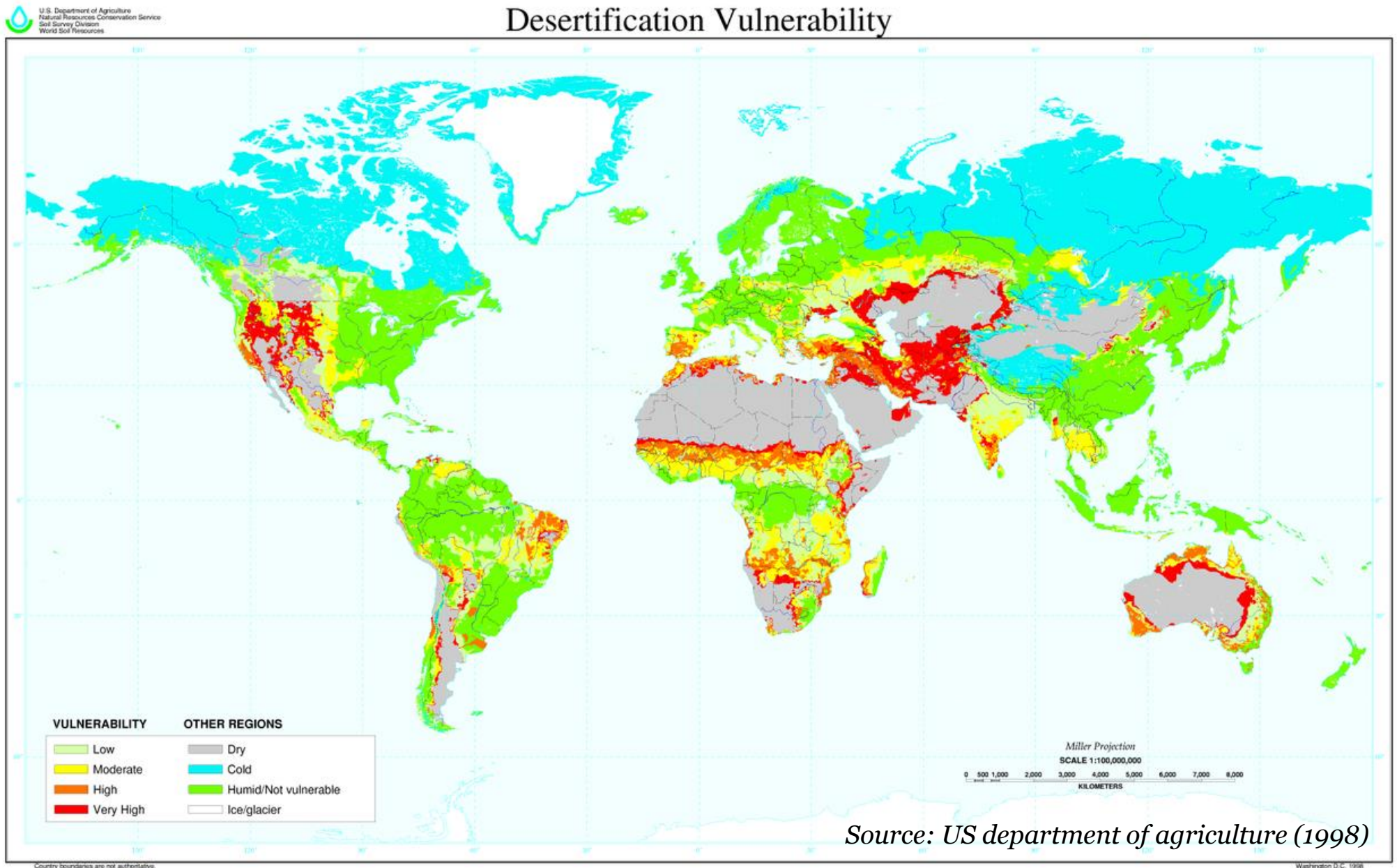
Universiteit Leiden
The Netherlands

Other people involved:		
Mathematicians	*Ecologists (theorists)*	*Ecologists (data scientists)*
❖ Olfa Jaïbi	❖ Koen Siteur	❖ Vincent Deblauwe
❖ Eric Siero	❖ Maarten Eppinga	❖ Stephane Mermoz
❖ Arjen Doelman	❖ Max Rietkerk	❖ Alexandre Bouvet

The desertification process

?

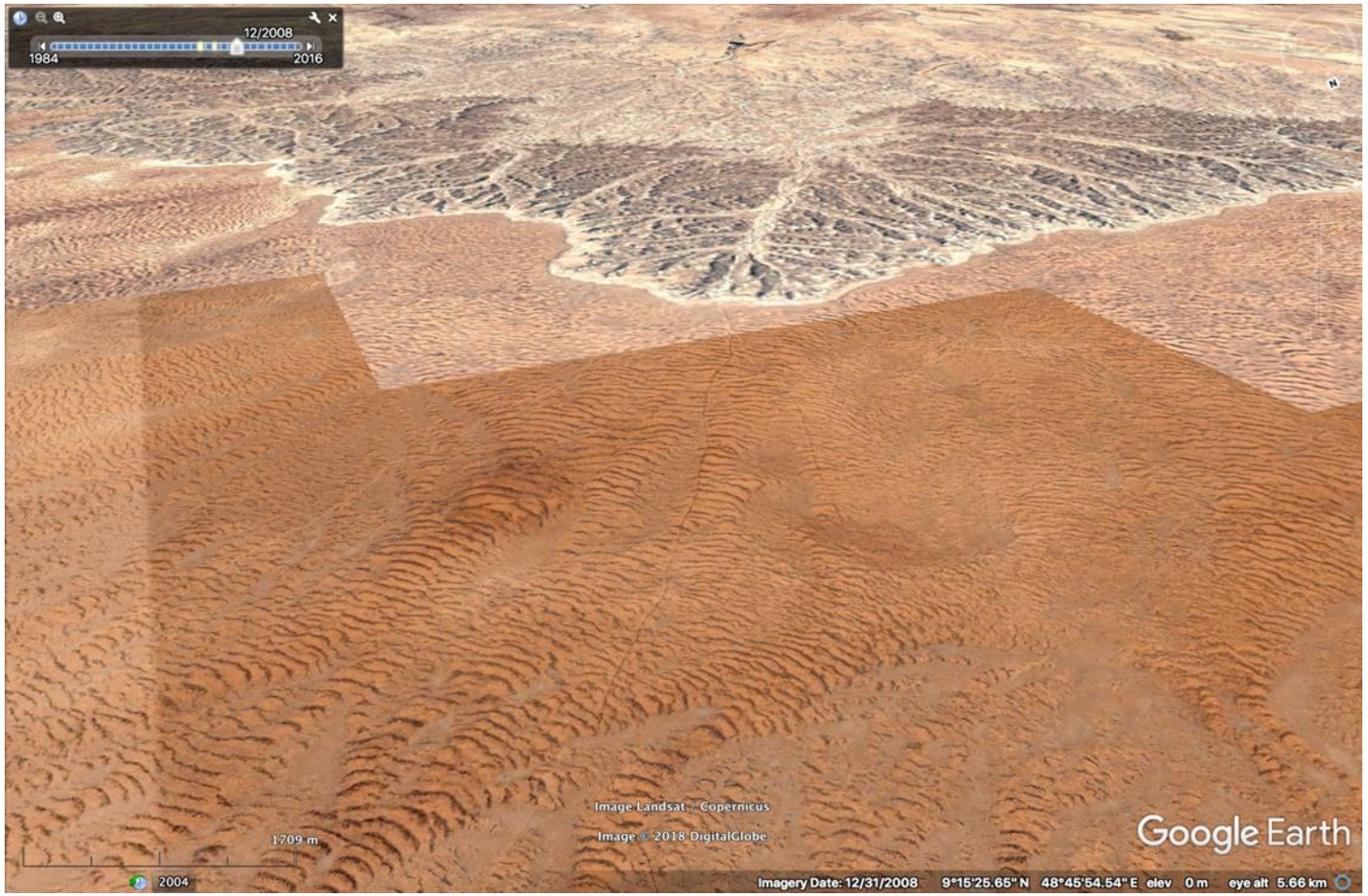
Desertification vulnerability



Source: US department of agriculture (1998)

Patterns are omnipresent in dryland ecosystems

Somaliland, 1948
Source: W. A. Macfadyen, *1950*

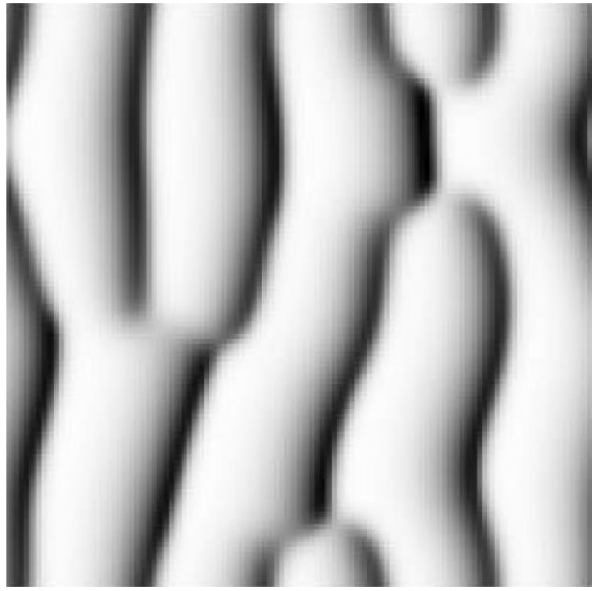


Somaliland, 2008
Source: Google Earth, 2018

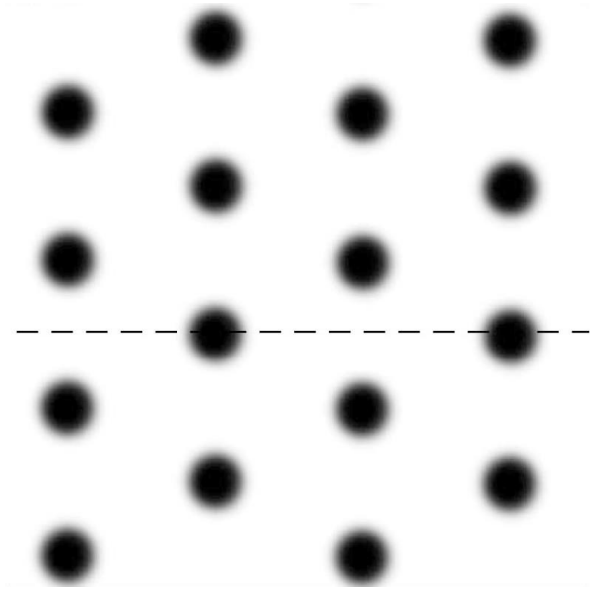
Reaction-diffusion equations model ecosystems

Archetype model: extended-Klausmeier model

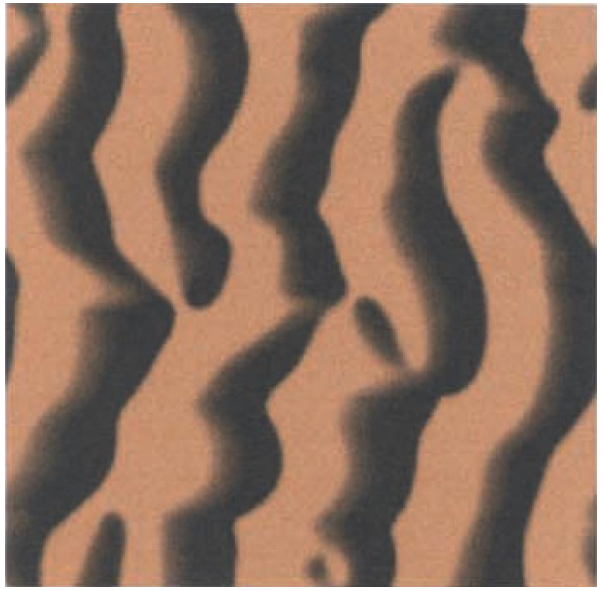
$$\begin{cases} \dfrac{\partial w}{\partial t} &= e\dfrac{\partial^2 w}{\partial x^2} + \dfrac{\partial (vw)}{\partial x} + a - w - wn^2 \\ \dfrac{\partial n}{\partial t} &= \dfrac{\partial^2 n}{\partial x^2} - mn + wn^2 \end{cases}$$



Source: Klausmeier, 1999

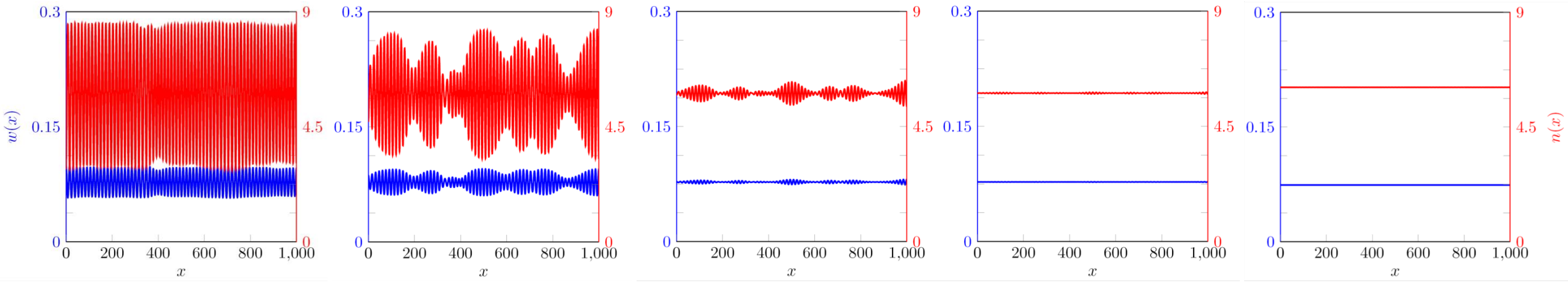


Source: Gilad et al, 2004



Source: Rietkerk et al, 2002

The origin of patterns in reaction-diffusion models



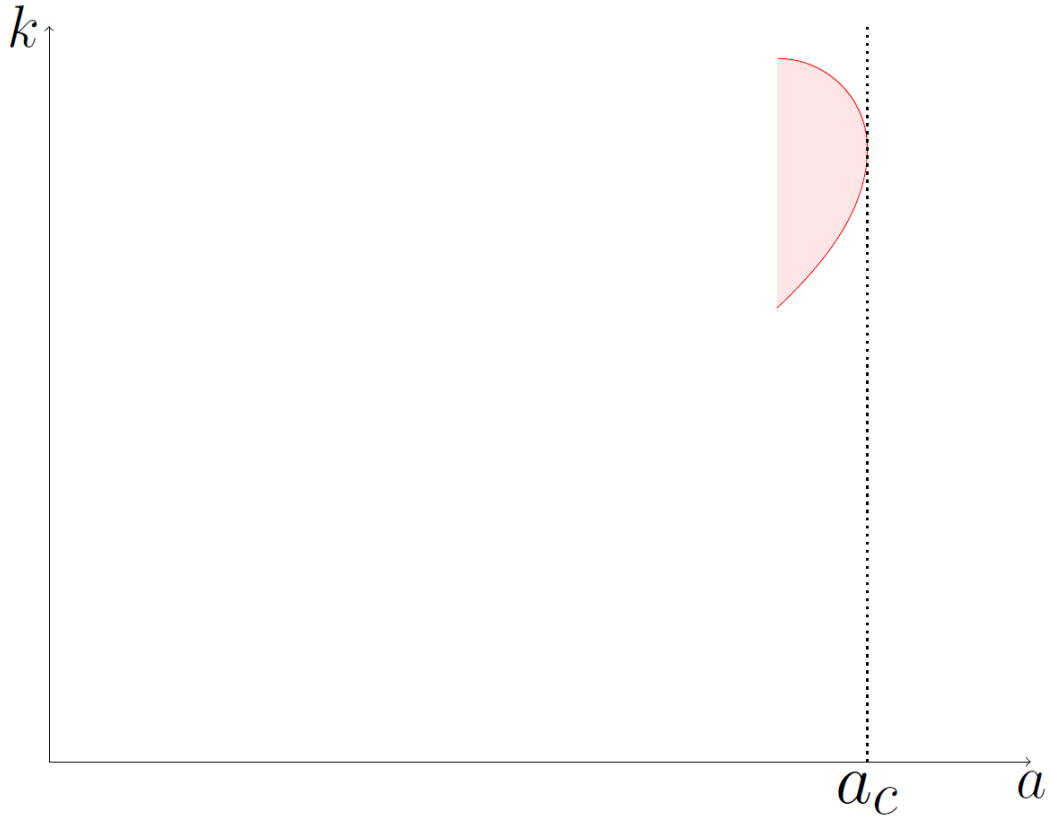
Low rainfall

Critical rainfall
Onset of patterns

High rainfall

Turing Patterns [Turing, 1952]
Found in most reaction-diffusion equations

Wavenumbers of Turing patterns

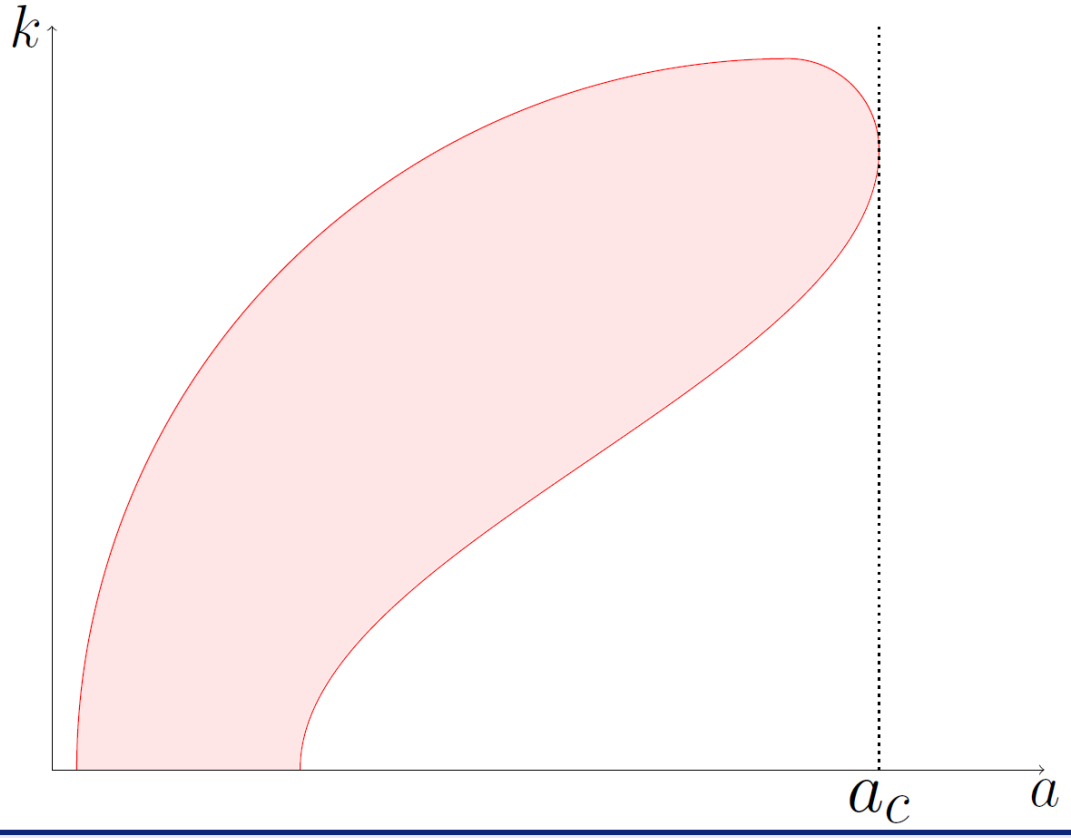


Eckhaus/Benjamin-Feir-Newell instability criterion

[Eckhaus, 1965; Benjamin & Feir, 1967; Newell, 1974]

Determination of the stable Turing patterns

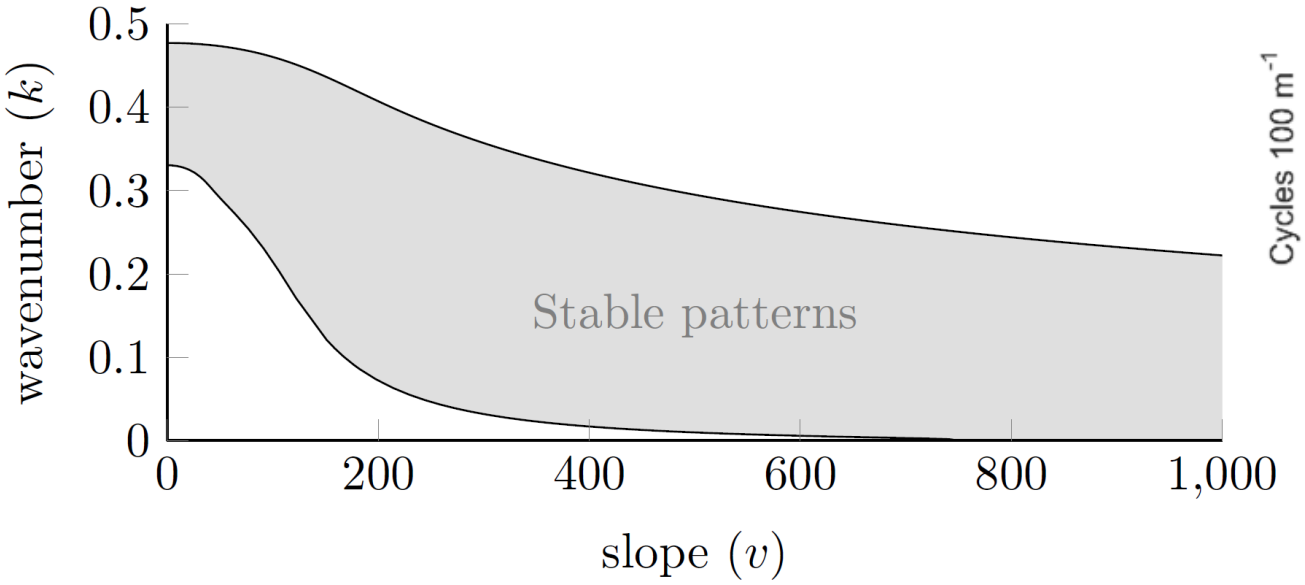
Busse balloon



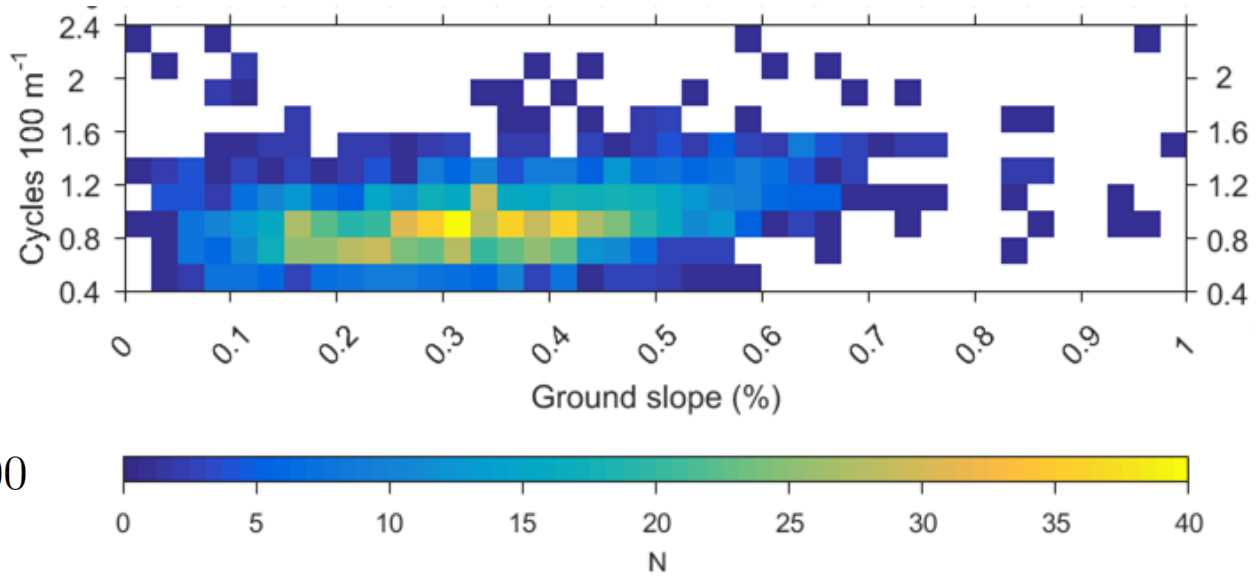
Busse balloon [Busse, 1978]

A *Busse balloon* is a model-dependent shape in (*parameter*, *wavenumber*)-space that indicates all combinations of parameter and wavenumber that represent stable solutions of the model

Busse balloon in dryland ecosystems



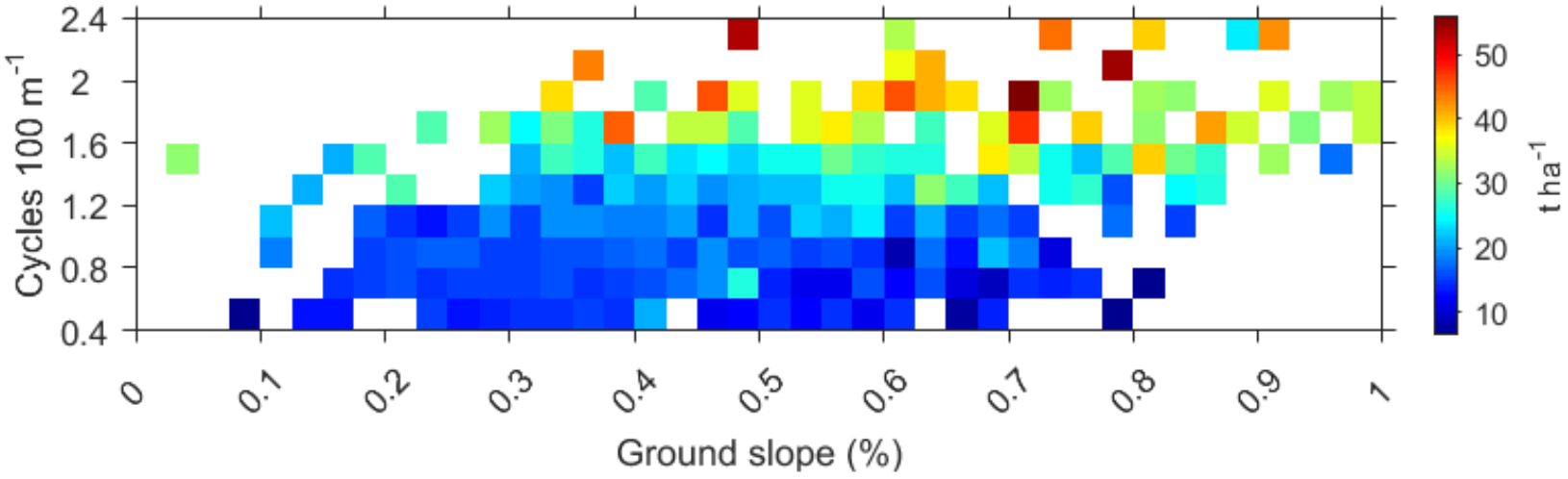
extended-Klausmeier model



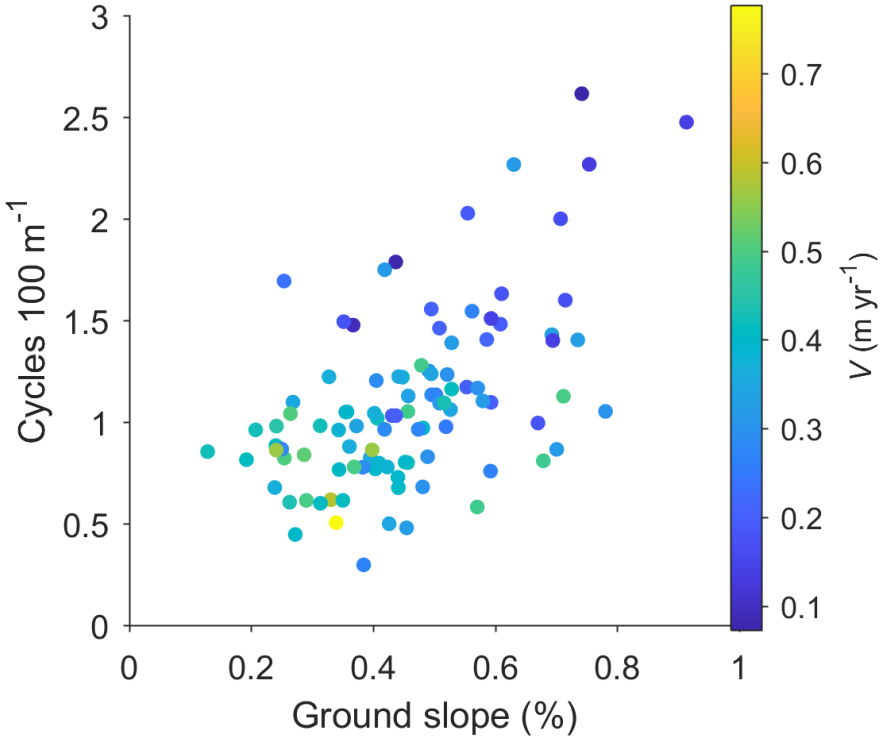
Somaliland data

Wide wavenumber spread in both!

Wavenumber influences state variables



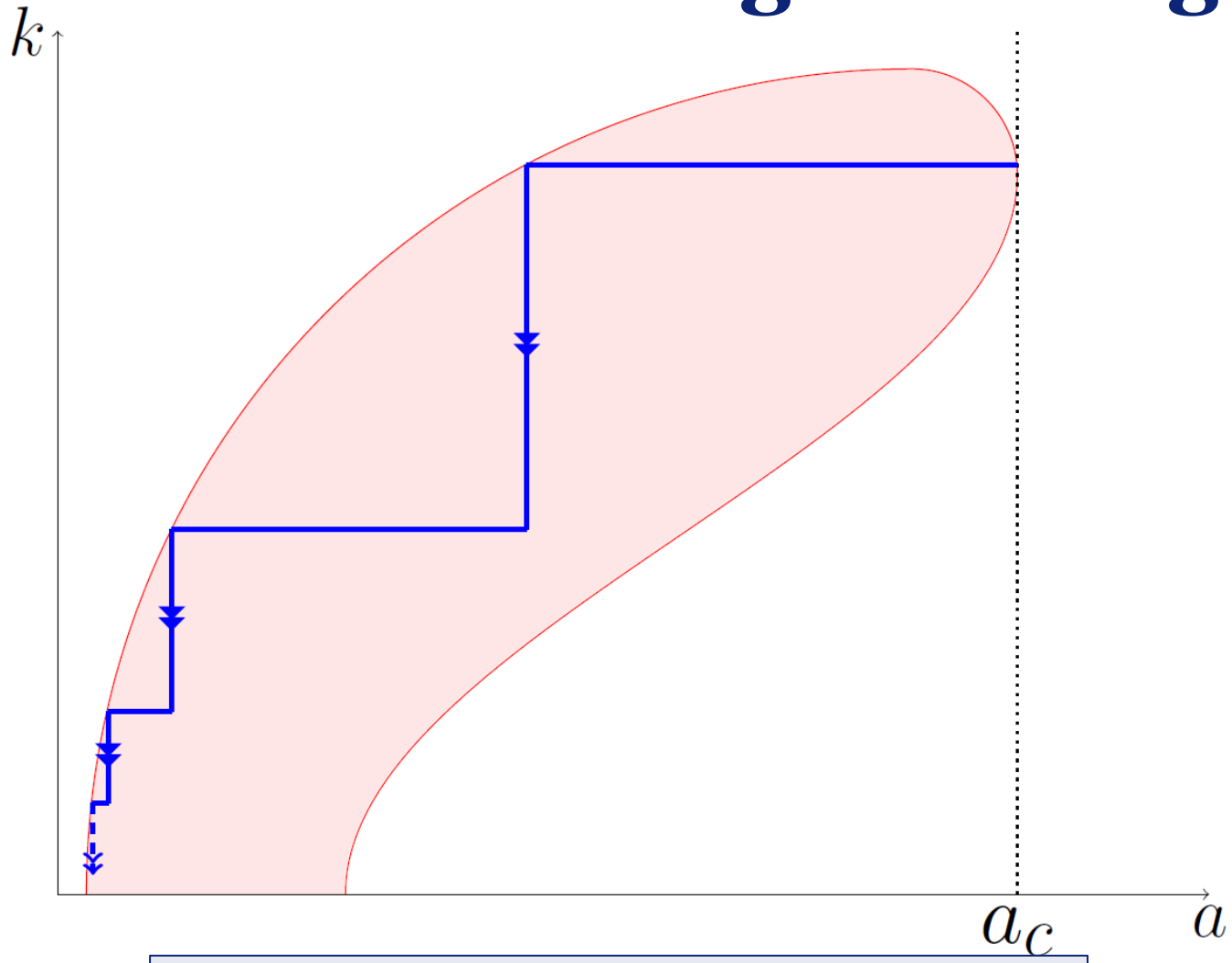
Biomass data



Migration speed data

Biomass and migration speed change with wavenumber!

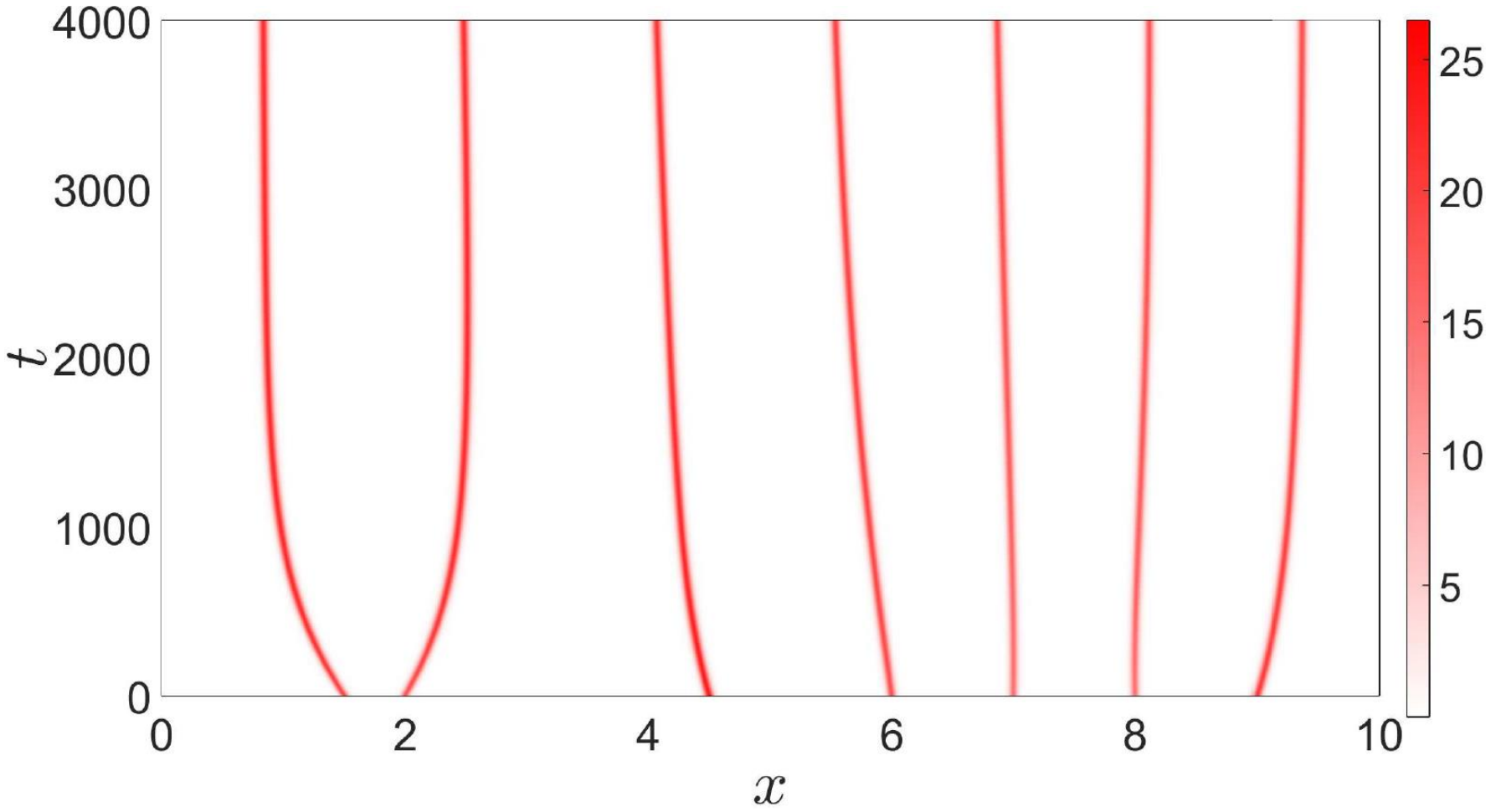
Enhanced resilience through self-organisation?



Wavelenght adaption

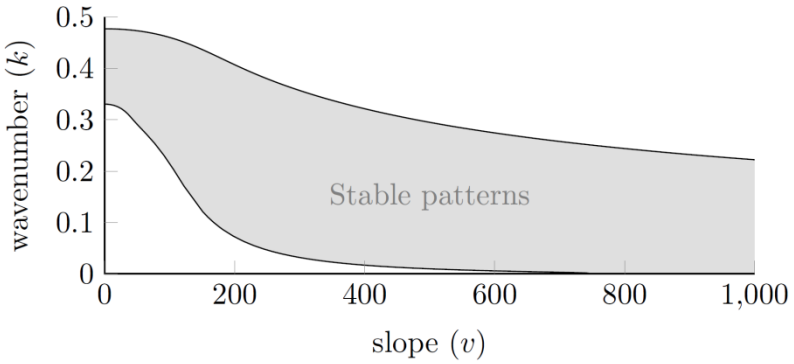
Siteur et al, 2014

Enhanced resilience through self-organisation?

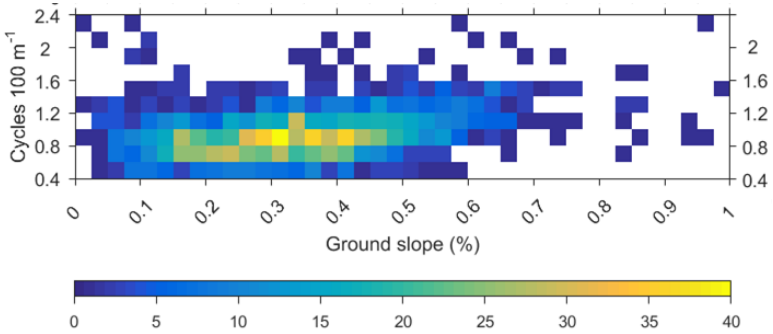


Pulse rearangement

Bastiaansen & Doelman, *submitted*



Conclusions



Wide wavenumber spread in model and real dryland ecosystems

implies

Biomass and migration speed change with wavenumber

and suggests

Enhanced resilience through self-organisation via …

Wavelength adaption

&

Pulse rearrangement