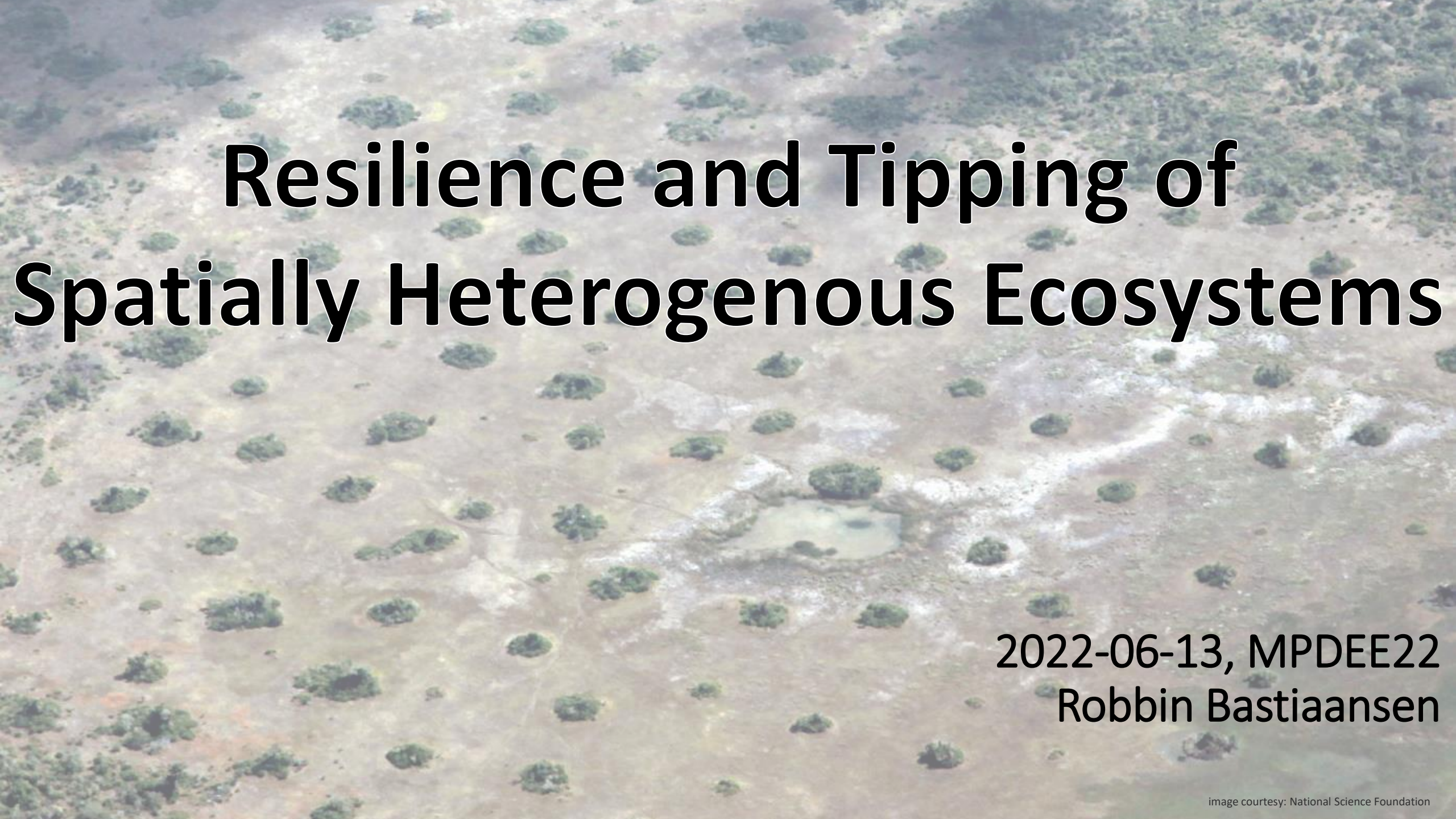
Resilience and Tipping of Spatially Heterogenous Ecosystems

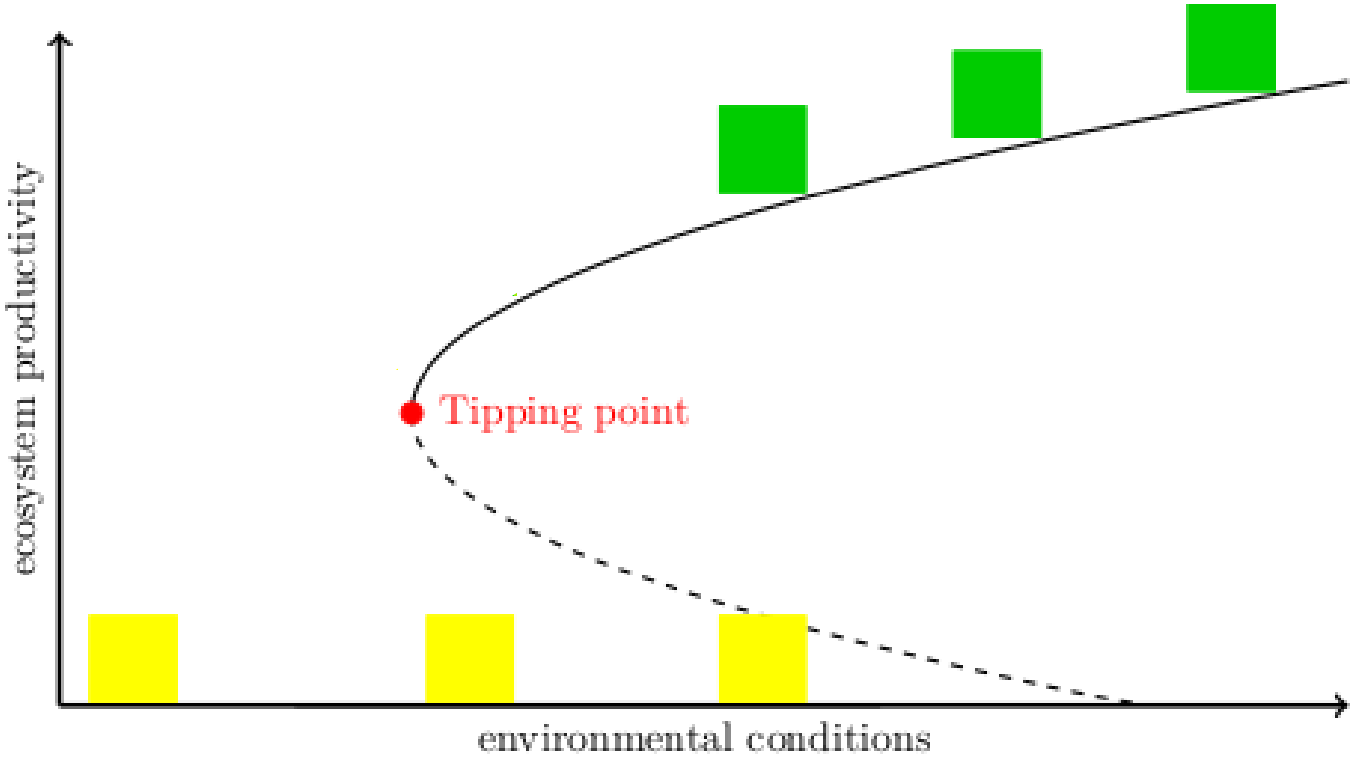


2022-06-13, MPDEE22

Robbin Bastiaansen

image courtesy: National Science Foundation

Classic view on resilience and tipping



Classic Literature
[Holling, 1973]
[Noy-Meier, 1975]
[May, 1977]

Recent Literature
[Ashwin et al, 2012]
[Steffen et al, 2018]

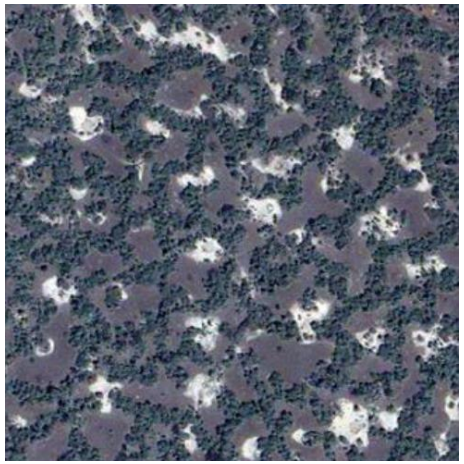
Tipping Points

IPCC AR6 (2021) : "a critical threshold beyond which a system reorganizes, often abruptly and/or irreversibly"

Examples of spatial Patterning

mussel beds

Algae bloom

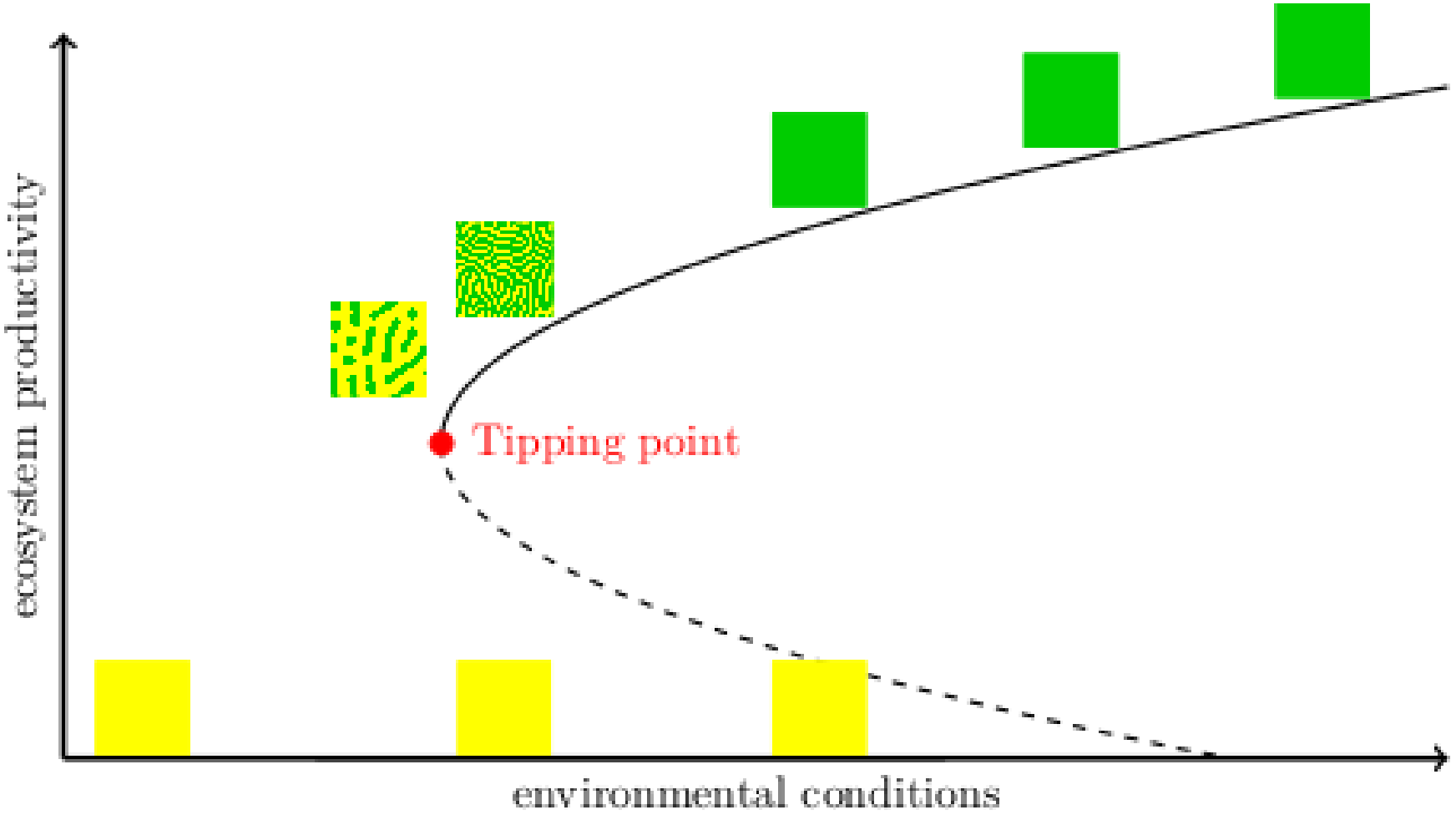


savannas

Forest-savanna interface

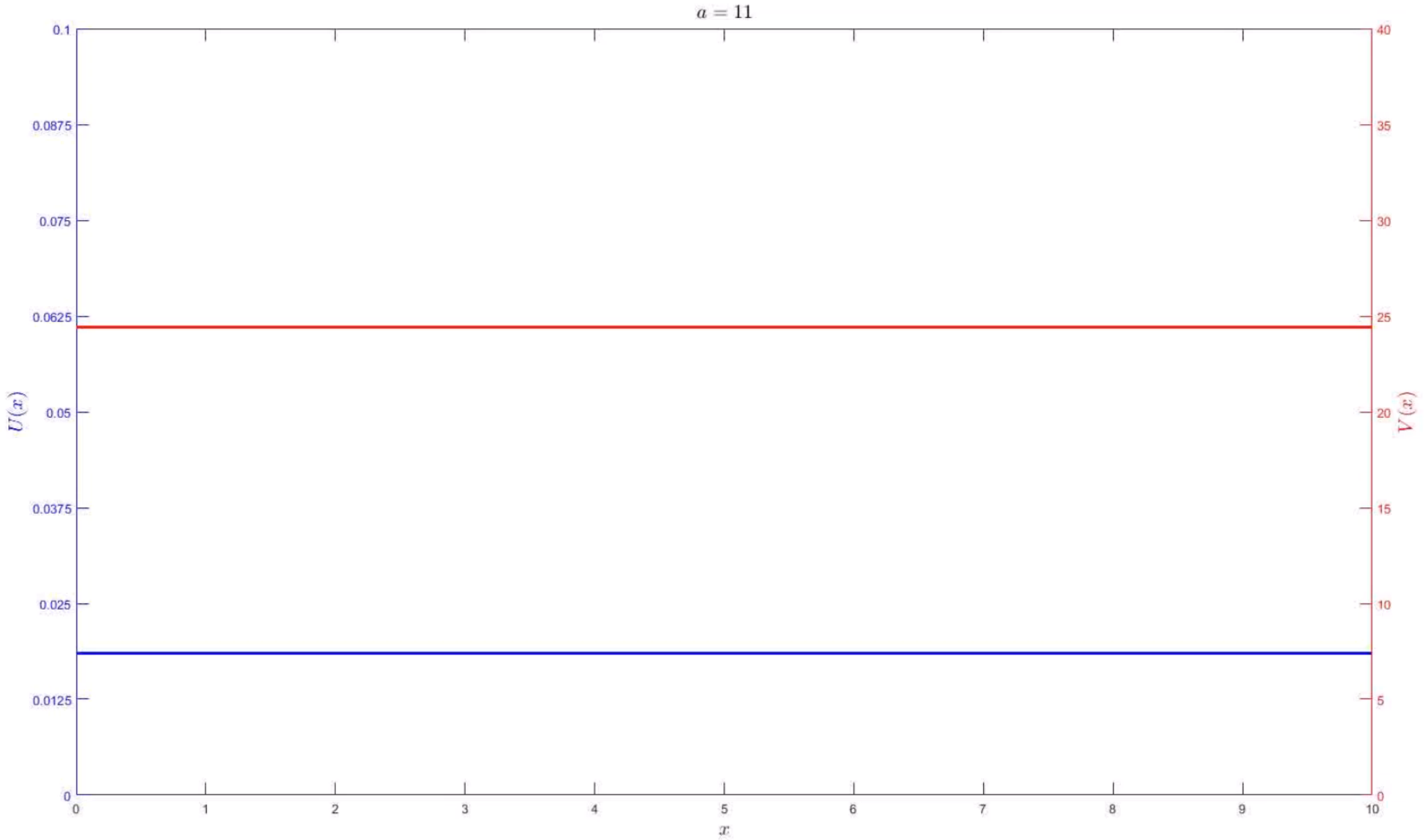
drylands

Classic view for spatially-structured systems

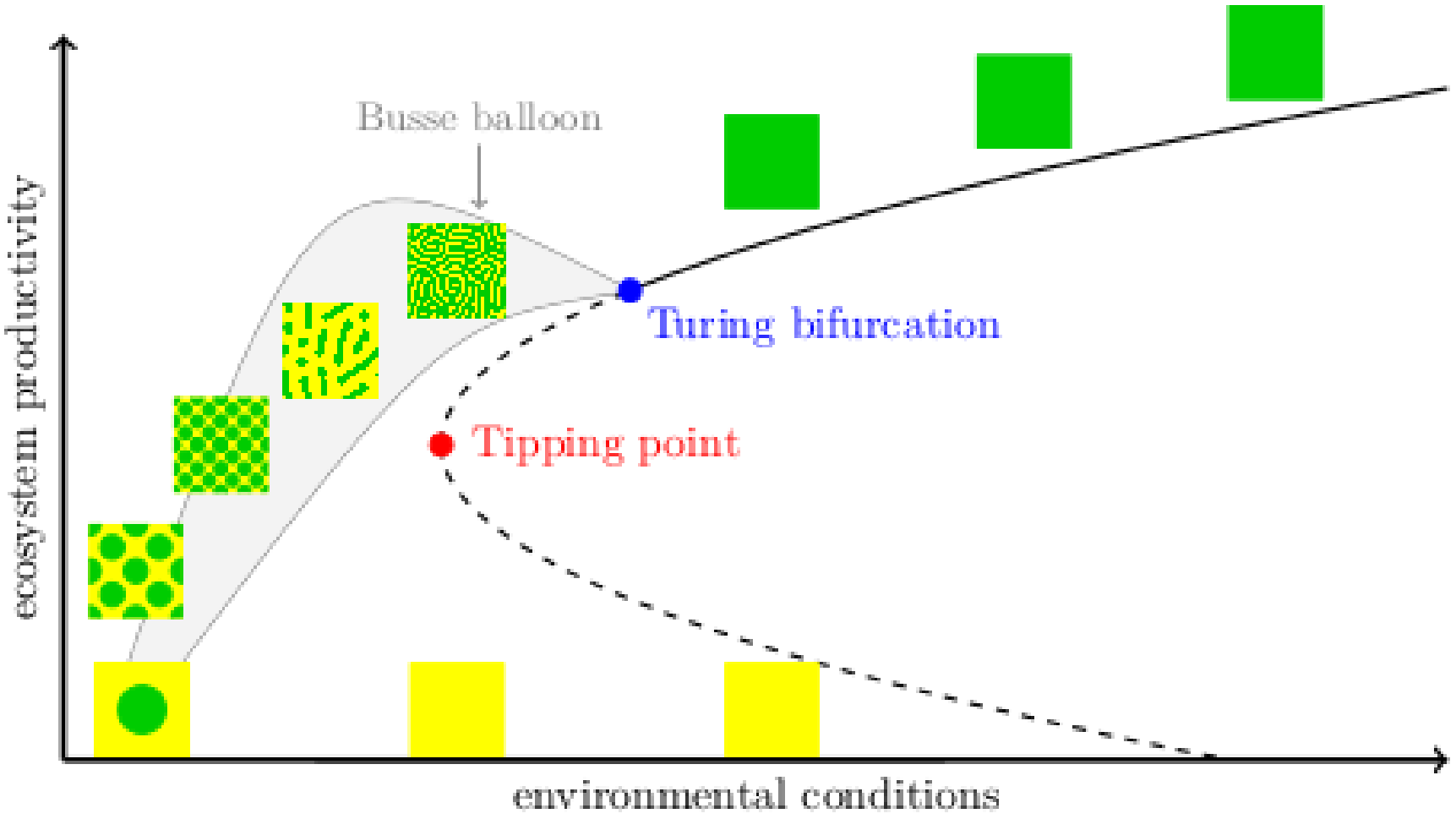


cf. e.g, [Rietkerk et al, 2004]

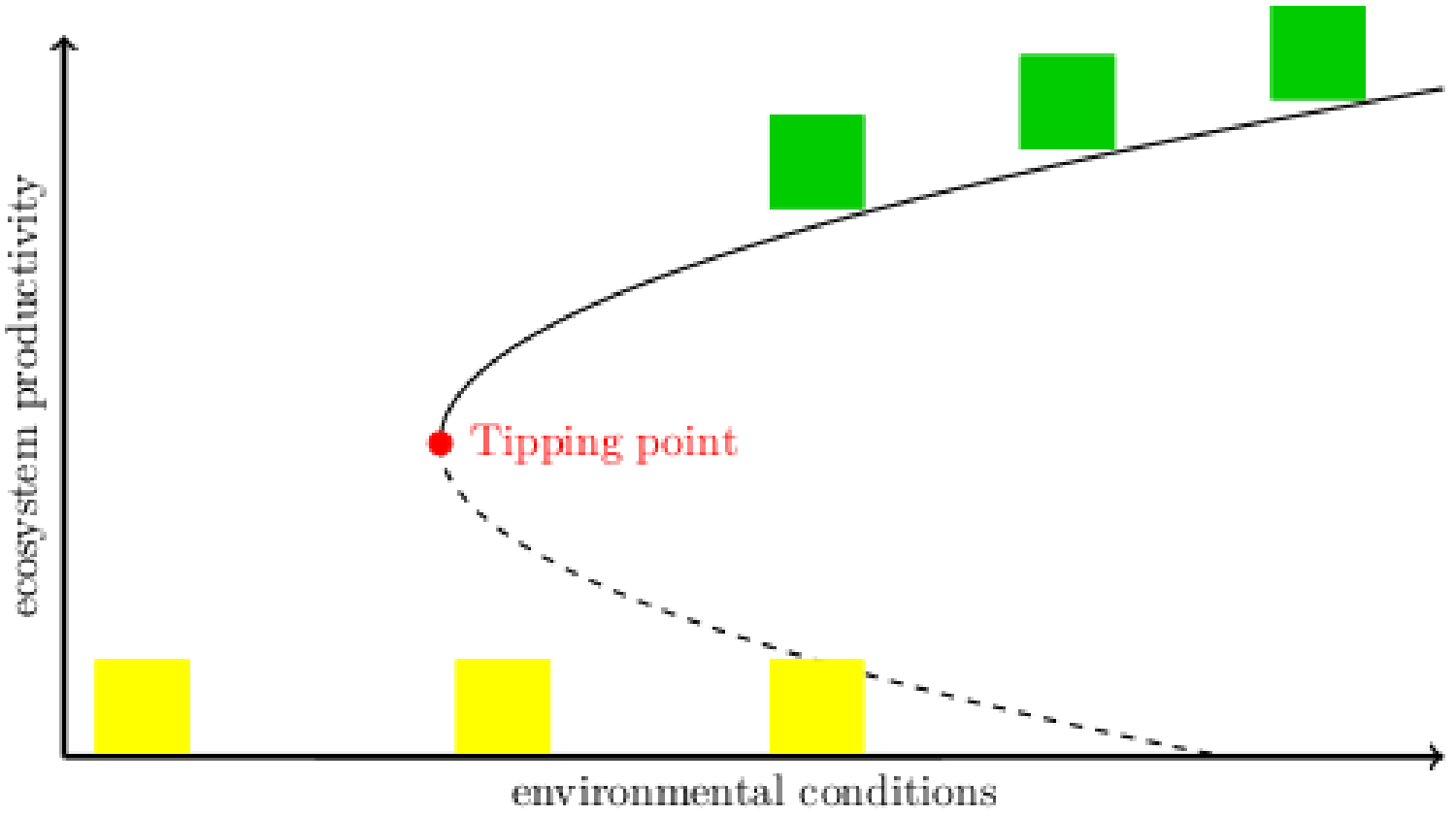
Behaviour of spatially-extended models



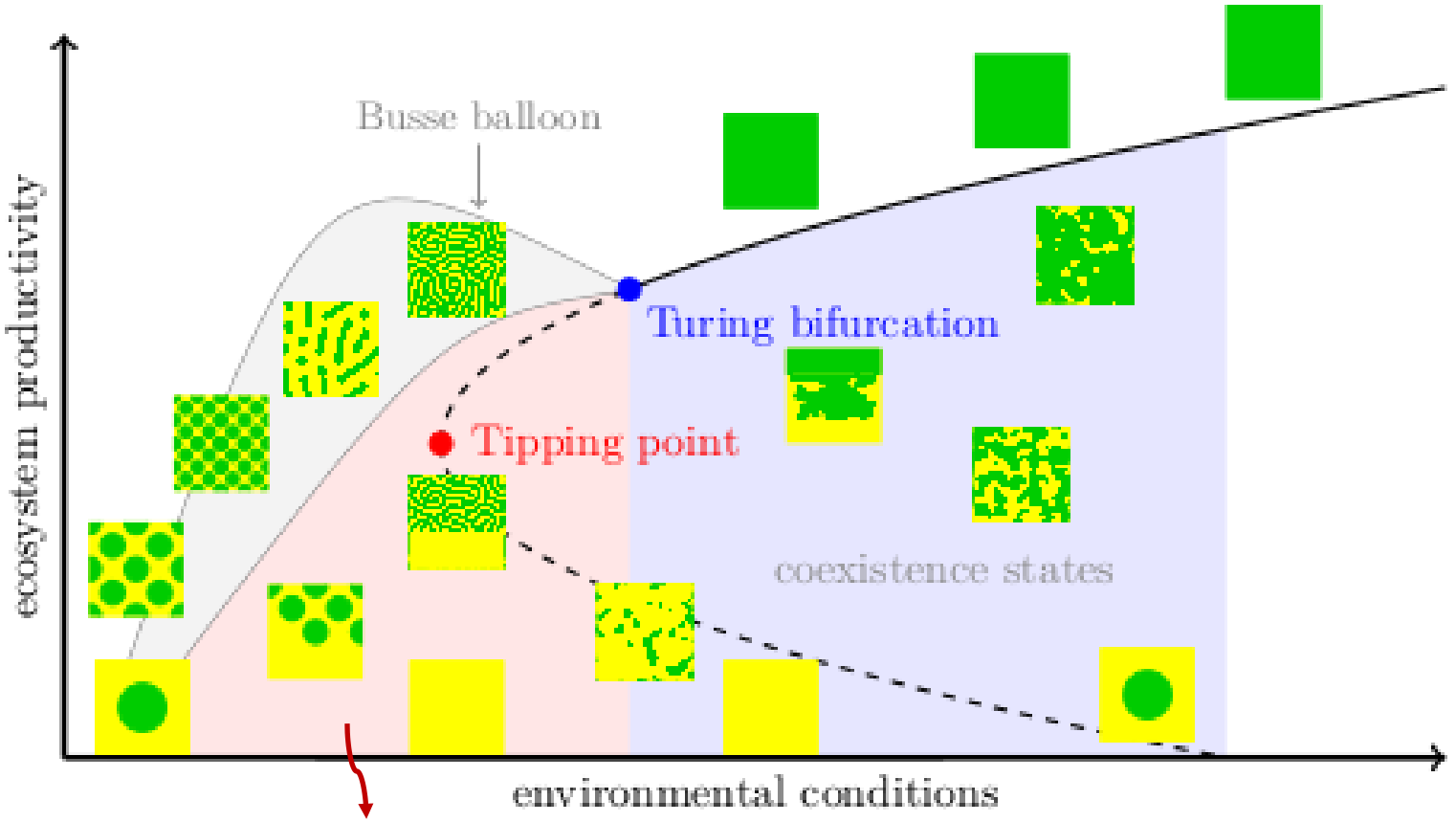
Multistability of Turing patterns



Coexistence patterns



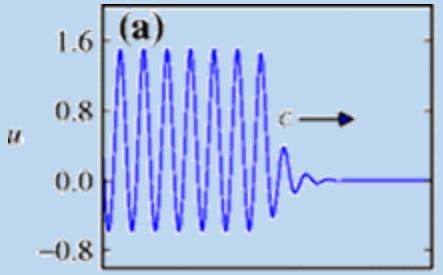
“Bifurcation Diagram” for spatially extended systems



Dynamics of patterns

1. SLOW Pattern Adaptation
2. FAST Pattern Degradation

Coexistence states between patterned and uniform states also exist



[Bel et al, 2012]

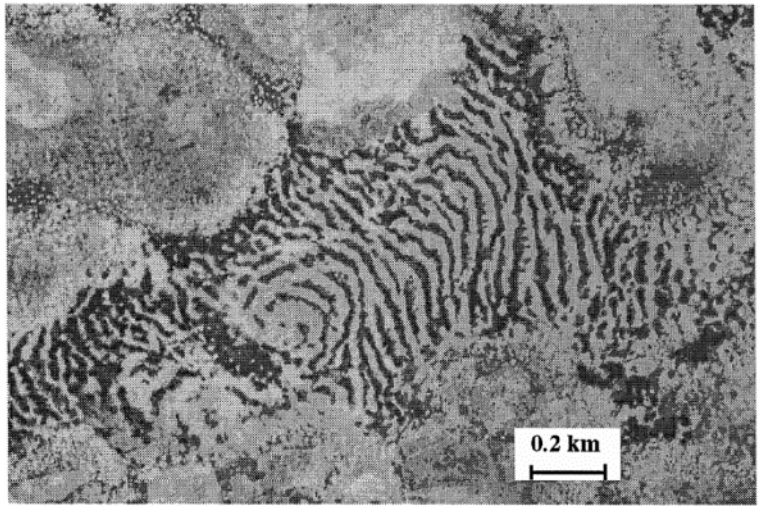
Bastiaansen, R., Doelman, A., Eppinga, M.B., Rietkerk, M. (2020). The effect of climate change on the resilience of ecosystems with adaptive spatial pattern formation. Ecology Letters 23:414-429

1. SLOW pattern adaptation

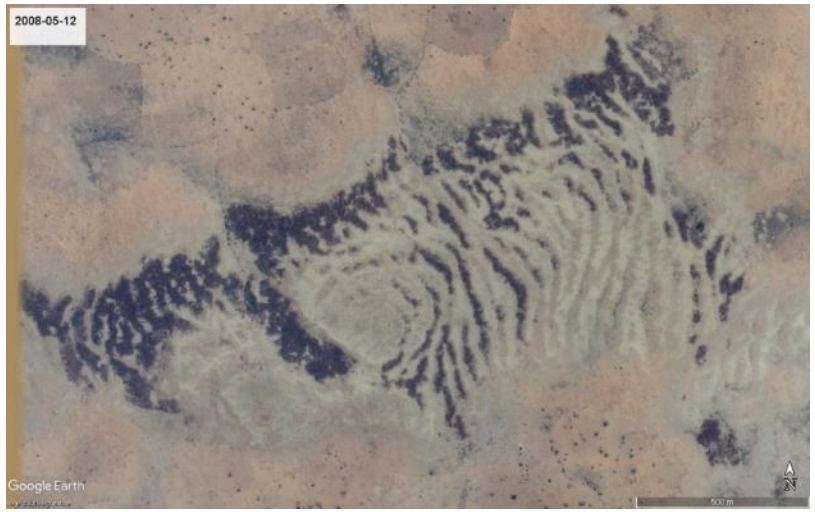
Somaliland, 1948 [Macfadyen, 1950]

Somaliland, 2008

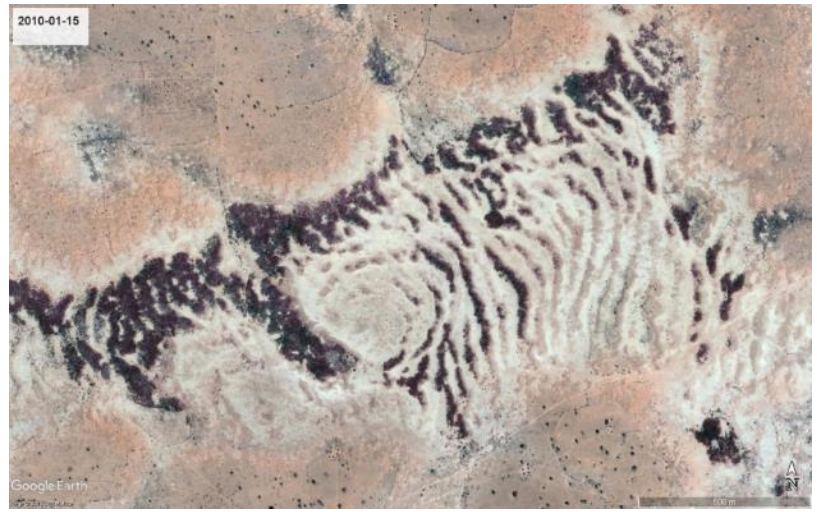
2. FAST Pattern Degradation



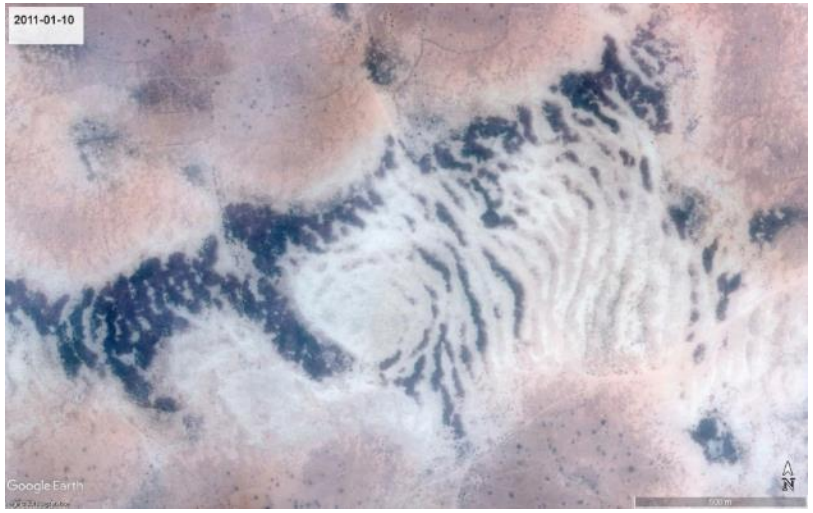
Niger, 1950 [Valentin, 1999]



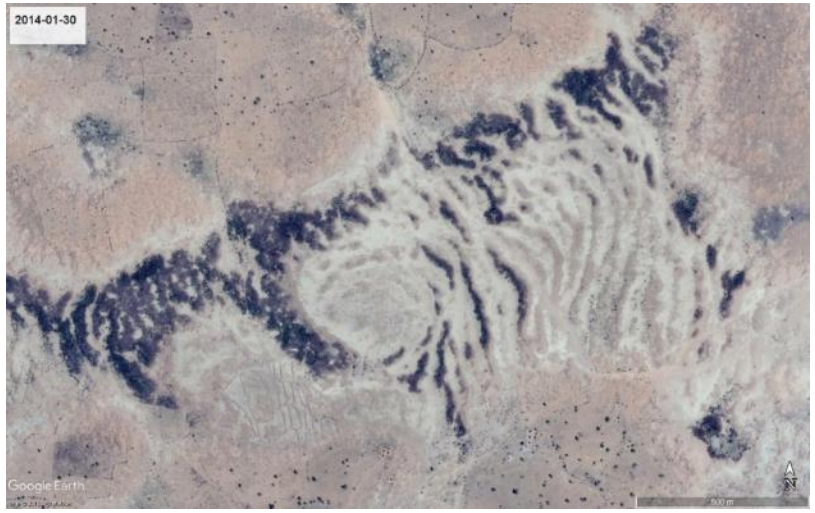
Niger, 2008



Niger, 2010



Niger, 2011



Niger, 2014

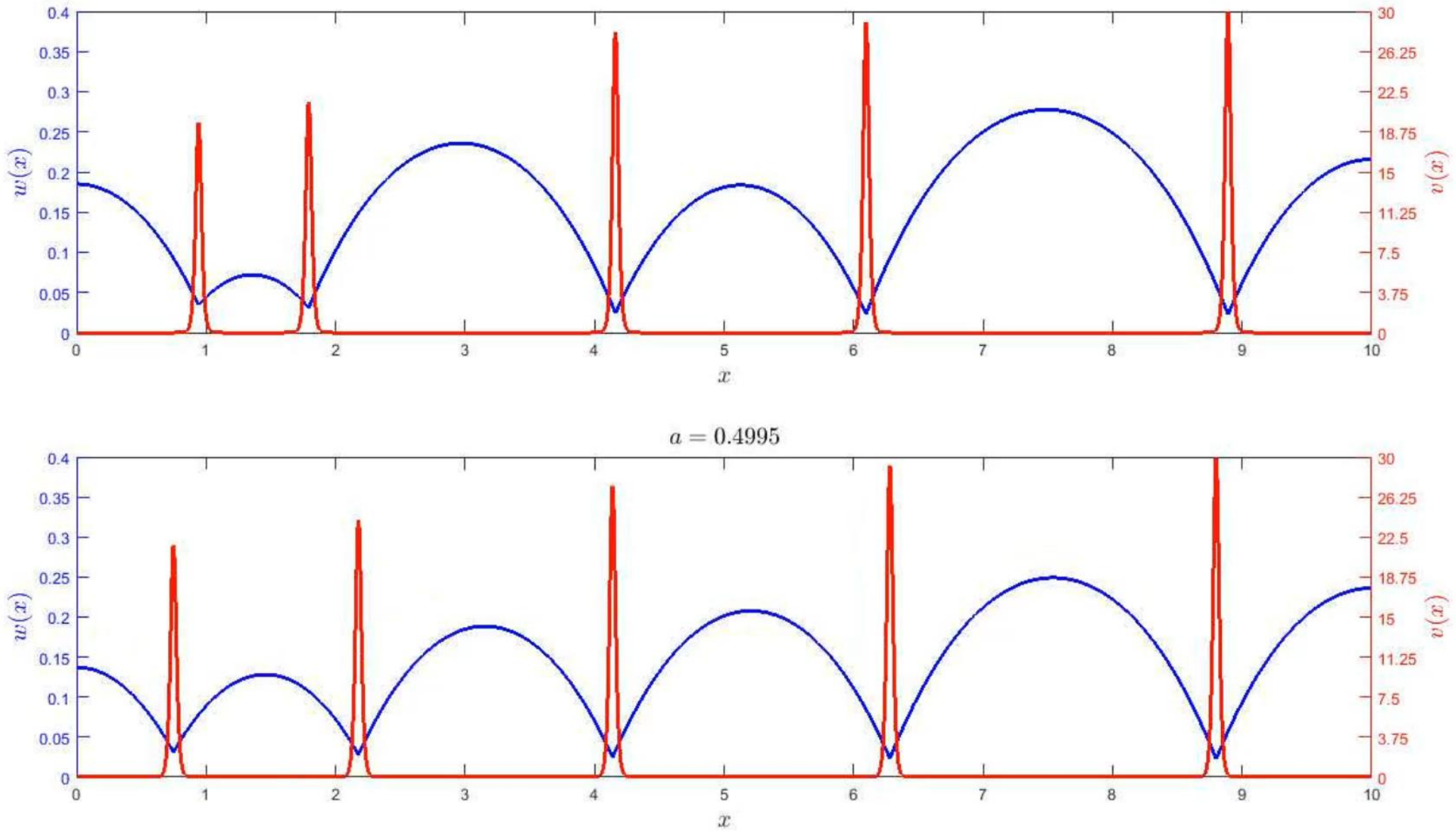
Niger, 2016

Vegetation patches under climate change

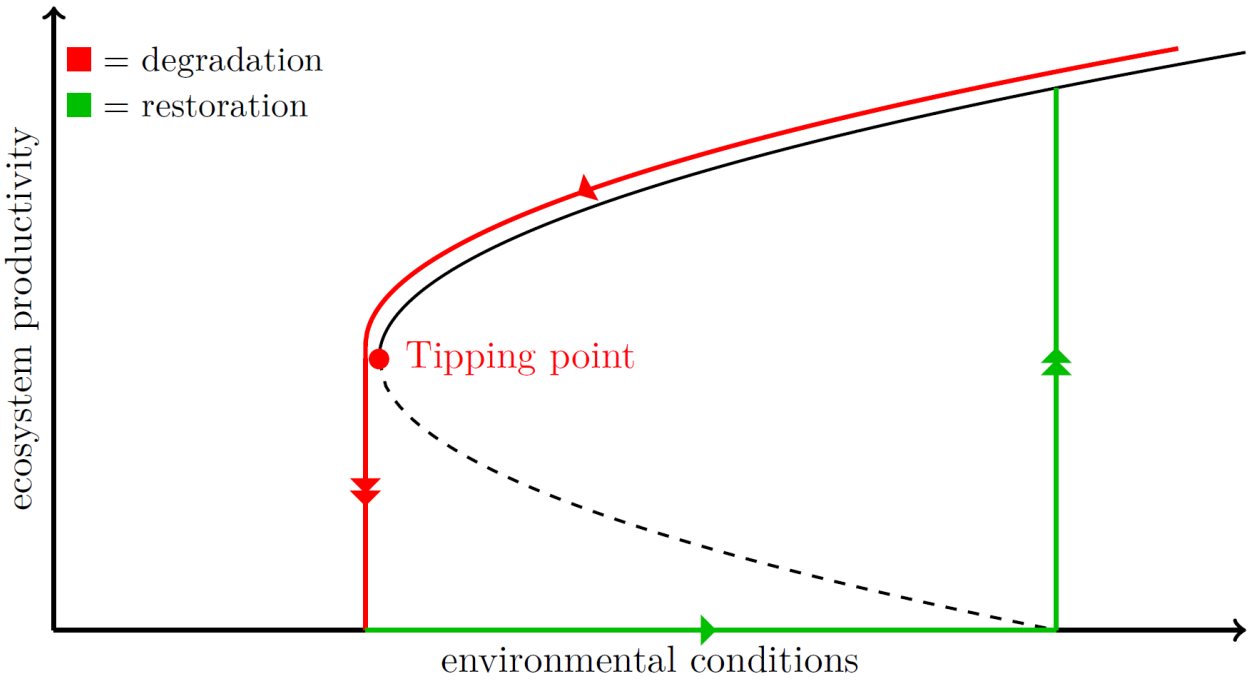
Rate of climate change

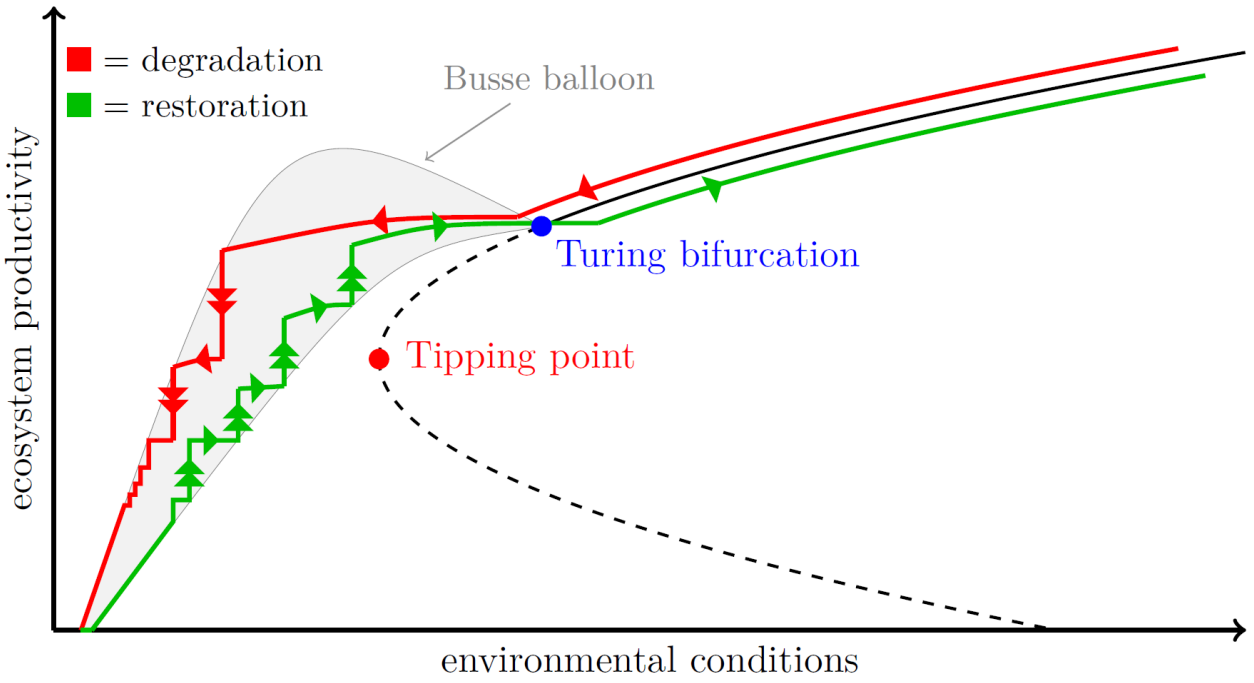
FAST

SLOW



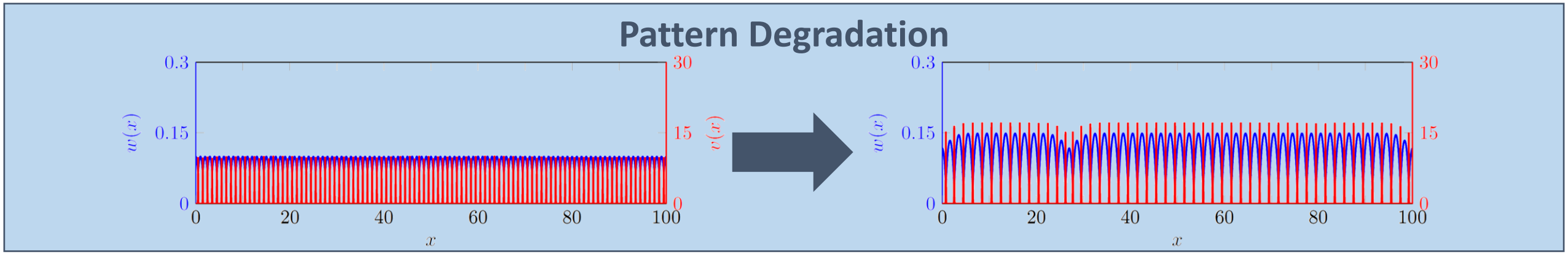
Tipping of (Turing) patterns



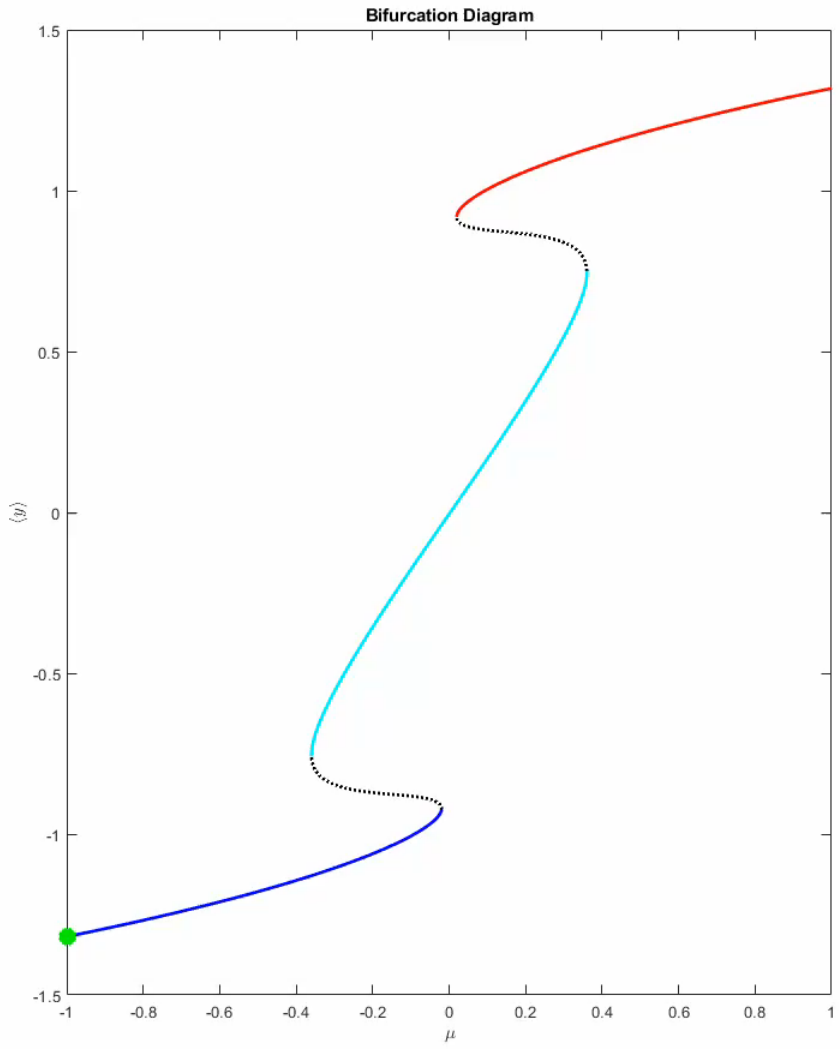


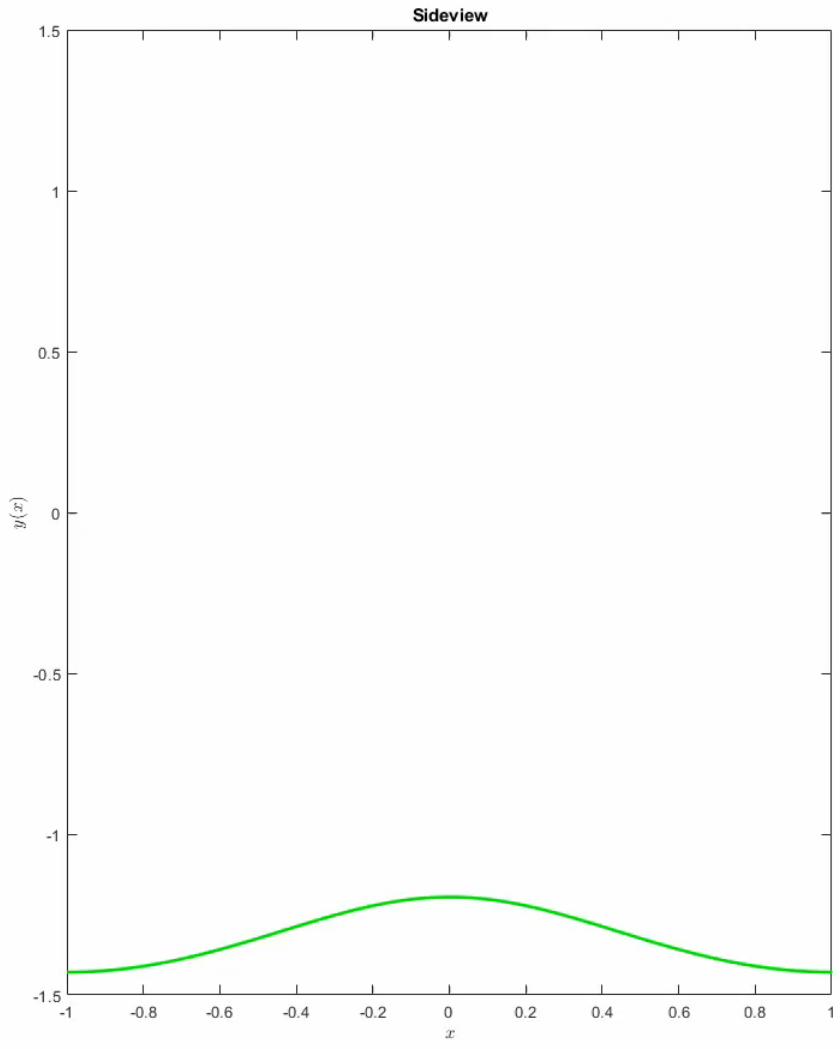
Classic tipping

Tipping of patterns



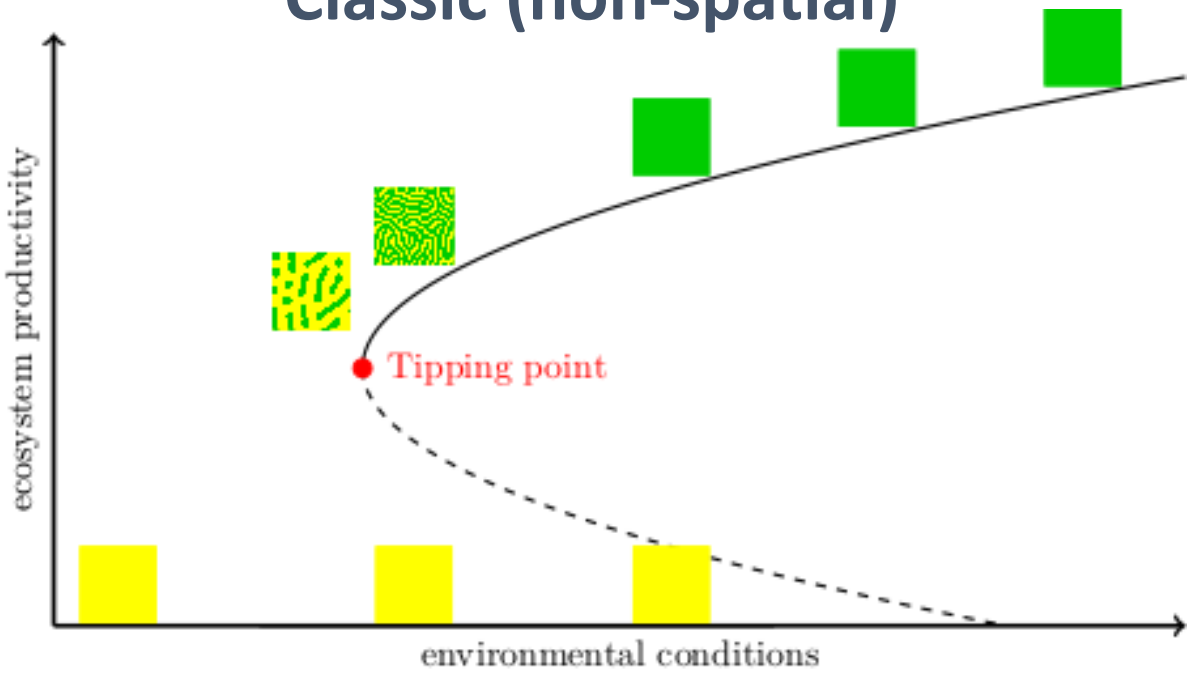
Fragmented tipping in a spatially heterogenous world





What if the system tips?

Classic (non-spatial)



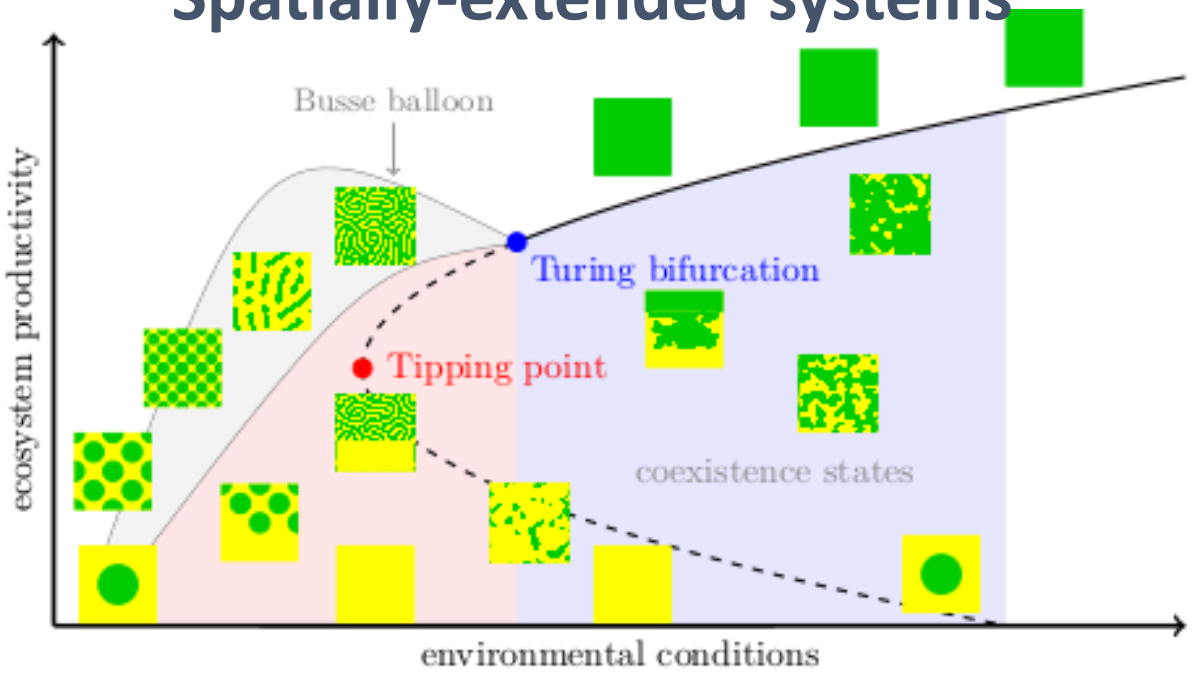
Crossing a Tipping Point:

→ Always full reorganization

Early Warning Signals

signal for <u>WHEN</u>

Spatially-extended systems



Crossing a bifurcation:

Now also possible:

→ Spatial reorganization (Turing patterns)

→ Fragmented tipping (coexistence states)

Early Warning Signals

need to signal <u>WHEN</u> & <u>WHAT</u>

Do systems always behave like this? (a.k.a. the small print)

No.

Well-mixed systems

Spatially confined systems

→ Such systems (again) behave like non-spatial models ←

But even in other systems terms & conditions apply:
System-specific knowledge is required!

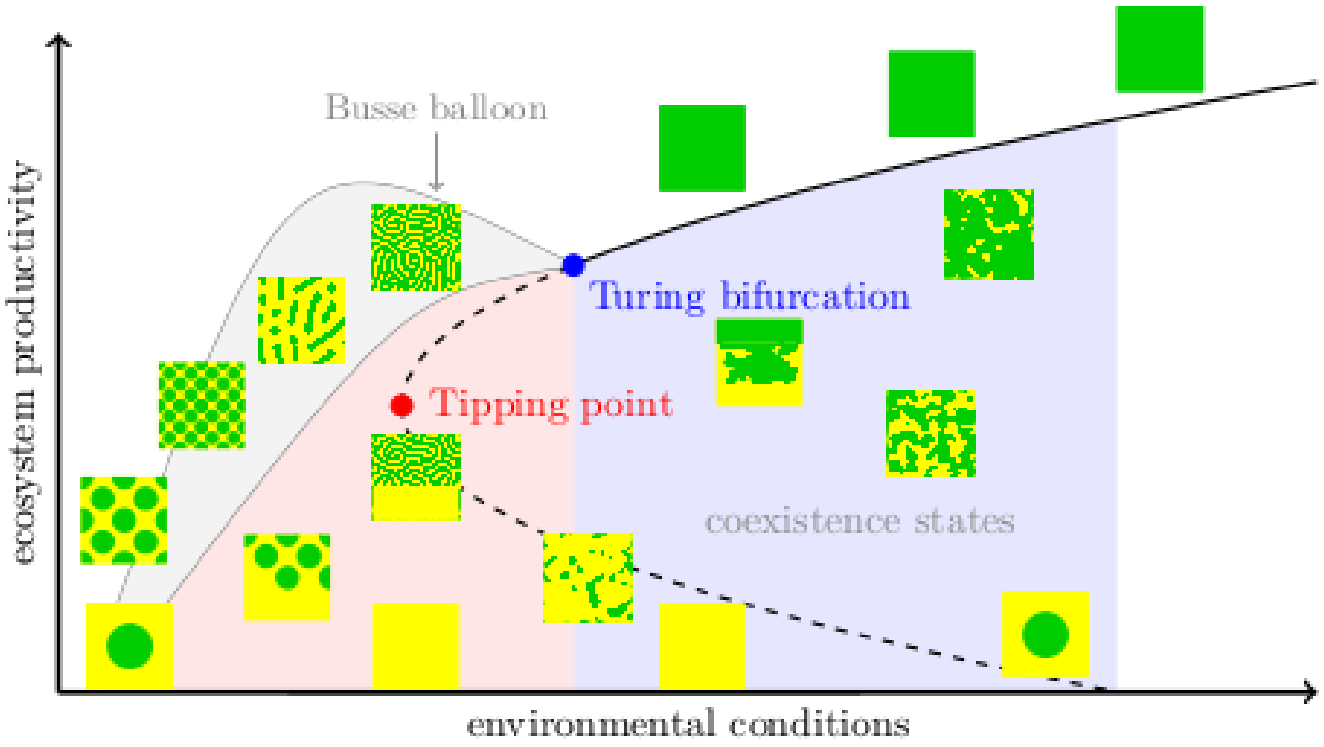
Summary

Spatial patterns:

- Turing Patterns
- Coexistence States

Tipping can be more subtle:

- Spatial reorganization
- Fragmented Tipping



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Rietkerk, M., Bastiaansen, R., Banerjee, S., van de Koppel, J., Baudena, M., & Doelman, A. (2021). Evasion of tipping in complex systems through spatial pattern formation. Science, 374(6564), eabj0359.

Bastiaansen, R., Dijkstra, H. A., & von der Heydt, A. S. (2021). Fragmented Tipping in a spatially heterogeneous world. *Environmental Research Letters, 17, 045006*