Universiteit Utrecht

Faculty of Geosciences
Copernicus Institute of Sustainable Development
Section of Environmental Sciences

Koen Siteur, Eric Siero, Maarten Eppinga, Jens Rademacher, Arjen Doelman, Max Rietkerk

Beyond Turing: The response of patterned ecosystems to environmental change

Universiteit Leiden
Universität Bremen
NWO
Nederlandse Organisatie voor Wetenschappelijk Onderzoek

Introduction

Currently, mathematical analysis of spatially explicit ecological models relies mainly on Turing analysis. Recently, mathematical techniques that go beyond Turing analysis have been applied to ecological models. Here we show how stability analysis on patterned system states helps in understanding the behavior of patterned ecosystems subject to environmental change.

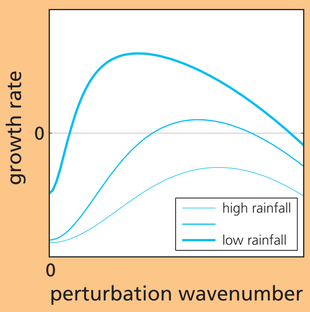
Turing analysis and beyond

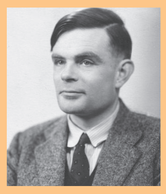
Turing prediction region

The stability of ecosystem states can be determined by adding perturbations

Turing stability analysis:
- considers stability of uniform system states
- assumes perturbations to be sinusoidal

Turing prediction region:
- here patterns can be expected, assuming that patterns adopt perturbation wavenumber when they form





Perturbations with a positive growth rate trigger pattern formation

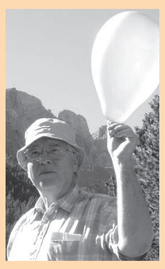
A.M. Turing (1912-1954)

Busse balloon

NEW

Busse balloon: region with stable patterns.

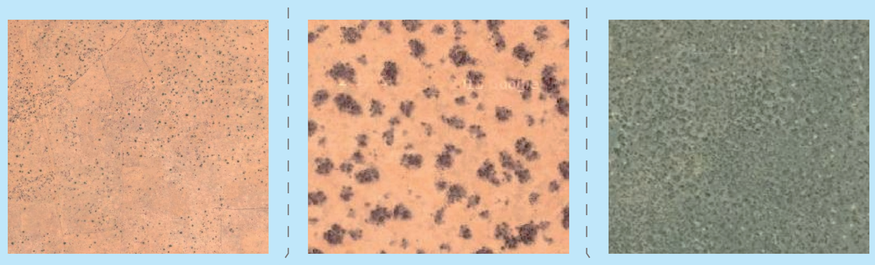
Notice that:
- Multiple stable patterned states exist.
- Pattern wavenumber decreases with rainfall.
- Only stable patterns can be observed, so:
  – patterns can be observed outside Turing prediction region.
  – not all patterns in Turing prediction region can be observed.

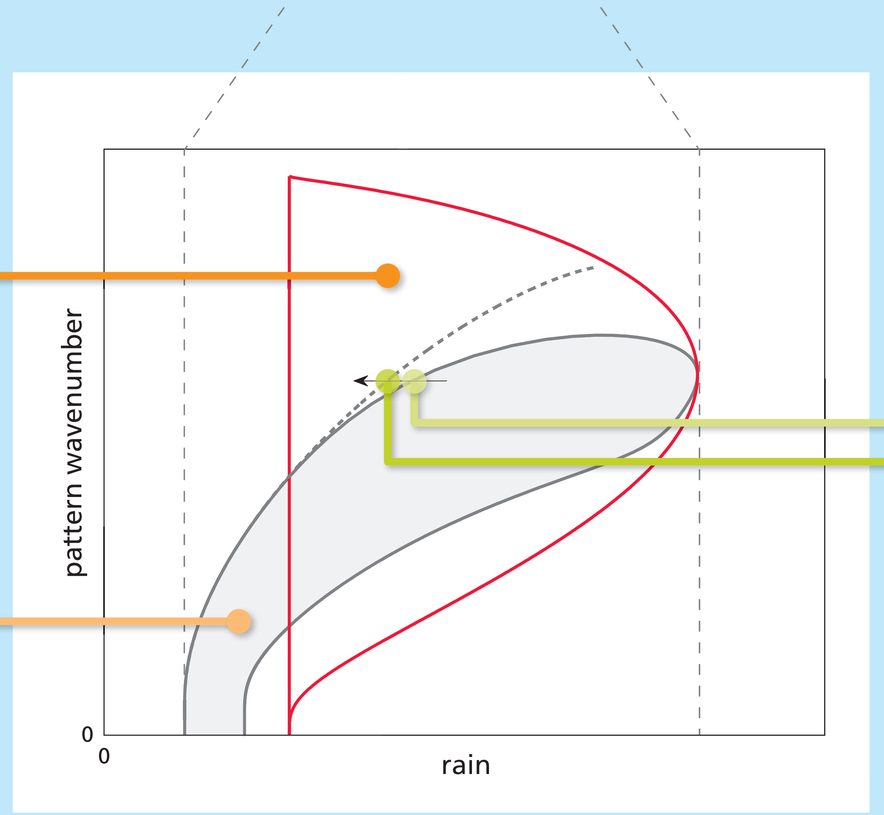


F.H. Busse

Stability regions for an arid ecosystem model

no vegetation | **patterned vegetation** | **uniform vegetation**





Stability regions. The wavenumber is inversely related to the space between patches.

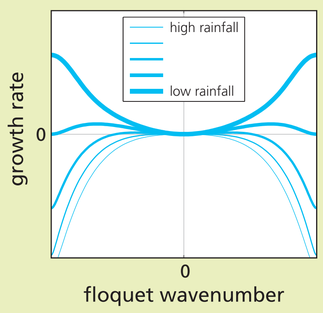
Environmental Change

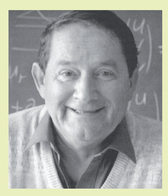
Rules of adaptation:
1. If system is in the Busse balloon: patch biomass changes
2. When system is forced outside the Busse balloon: pattern wavenumber changes

Sideband instability

NEW

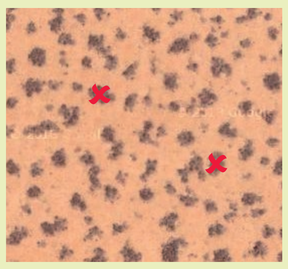
If rainfall declines, the system leaves the Busse balloon and first encounters the sideband instability.
Here patches go extinct, resulting in a lower wavenumber.





Perturbations with a positive growth rate destabilize a pattern

W. Eckhaus (1930-2000)

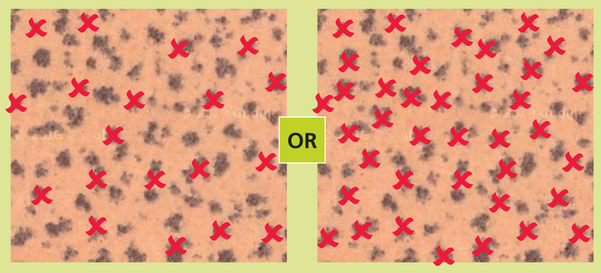


One-by-one extinction of patches

Period doubling instability

NEW

If change in rainfall is rapid, the system also crosses the period doubling instability. Here half or all patches go extinct simultaneously.



Extinction of half of the patches

Extinction of all patches

Conclusion

Knowledge about the stability and destabilization of patterned ecosystem states is essential for understanding the response of patterned ecosystems to environmental change.

References

Busse, F., 1978. Non-linear properties of thermal convection. Reports on Progress in Physics, 41, 1929-1967.

Siteur, K., E. Siero, M.B. Eppinga, J.D.M. Rademacher, A. Doelman & M. Rietkerk, 2014. Beyond Turing: The response of patterned ecosystems to environmental change. Ecological Complexity, 20, 81-96.

Turing, A. M., 1953. The chemical basis of morphogenesis. Bulletin of mathematical biology, 237, 37-72.

Layout: C&M - Faculty of Geosciences - ©2014 (8772)