Gene drives touching Tipping Points

Broder Breckling
Arnim von Gleich

Universität Vechta
University of Vechta

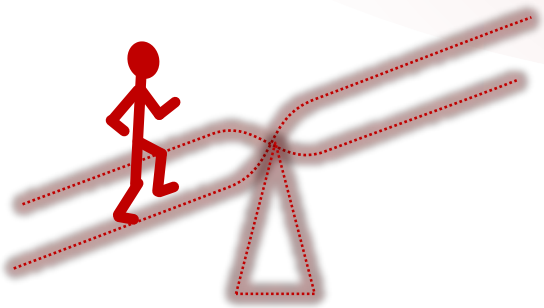
Universität Bremen

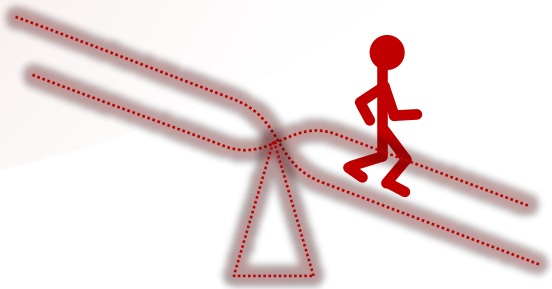
Overview

- Conceptual context:
  Prototypic tipping point examples
- Formalisations
  and model representations
- Discusson of
  gene drive related tipping points

Conceptual context:

Prototypic
tipping point
examples





Background

Tipping point is a metaphoric description of a sudden, eventually unexpected and self-enforcing change emerging from a relatively minor impact (Gladwell 2006).

For scientific use, the intuitive understanding of the concept receives a formal operationalisation to avoid conceptual ambiguity.

Related context:

- Phase shift (~ phase transition, regime shift)
- Bifurcation
- Hysteresis
- Outbreak dynamics
- Chain reaction …

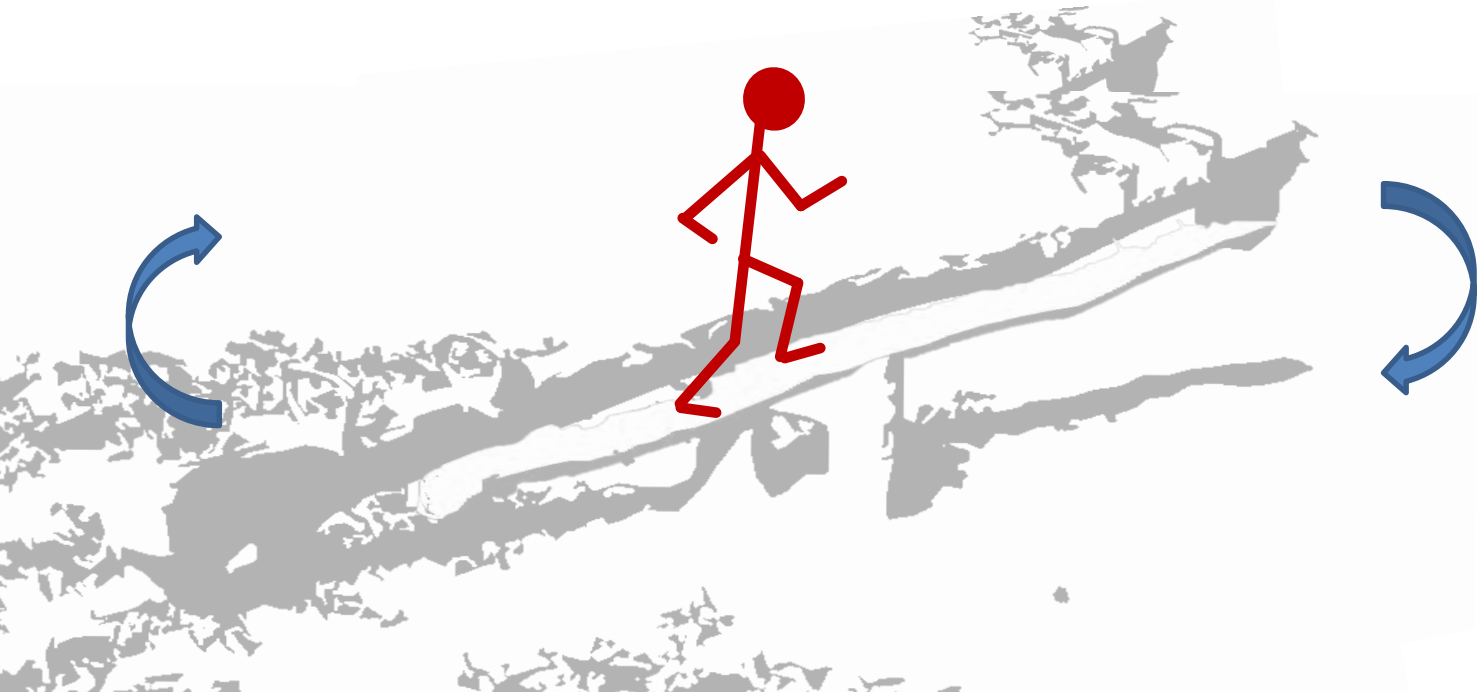
Gladwell, M. (2006). The tipping point: How little things can make a big difference. Little, Brown.

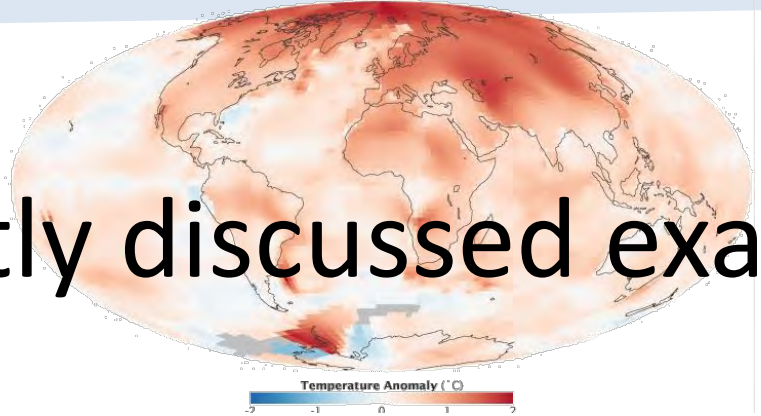
Playground experience

- Seesaw

Tipping point refers to a **Singularity**:

At the tipping point, *infinitesimally* small impact can shift the balance





Frequently discussed examples

Self-enforcing functional feedback in global climate change

- CO_2 mediated global warming
  - Increased CO_2 -> increases greenhouse effect -> increases temperature -> increases soil organic matter decomposition -> increases CO_2 …
- Greenland ice shield melting
  - Global warming -> reduces greenland ice shield -> reduces albedo -> increases global warming …
- Methane hydrate release
  - Ocean warming ->methane hydrate instability -> methane release to the atmosphere -> global warming -> ocean warming …

https://de.wikipedia.org/wiki/Globale_Erw%C3%A4rmung https://en.wikipedia.org/wiki/Iceberg

Prototypic examples

Outbreaks

- Infections, diseases, pests
- Ecological invasions
- Plankton blooms
- Forest fires

A rapidly expanding process that emerges, once a threshold was passed. The transition amplifies across several orders of magnitude and can persist or collapse.

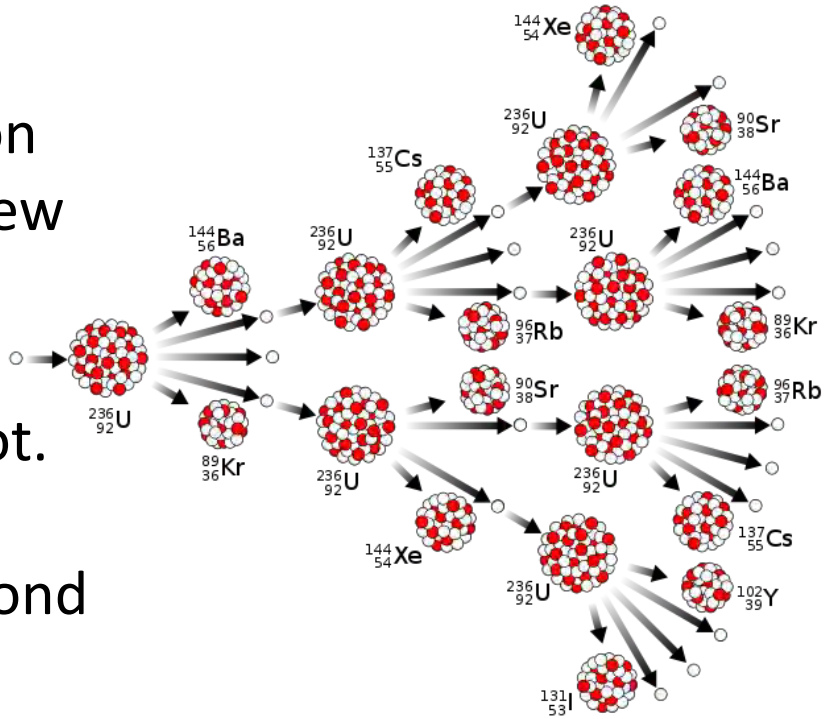
https://pt.wikipedia.org/wiki/Mar%C3%A9_vermelha
https://commons.wikimedia.org/wiki/File:Fire-Forest.jpg

Prototypic examples

Statistical Physics:

Critical mass effect

If neutrons resulting from nuclear fission generate on average more than one new neutron, a nuclear chain reaction is sustained, otherwise not. This occurs in particular radioactive materials beyond a threshold.



https://commons.wikimedia.org/wiki/File:Nuclear_fission_chain_reaction.svg

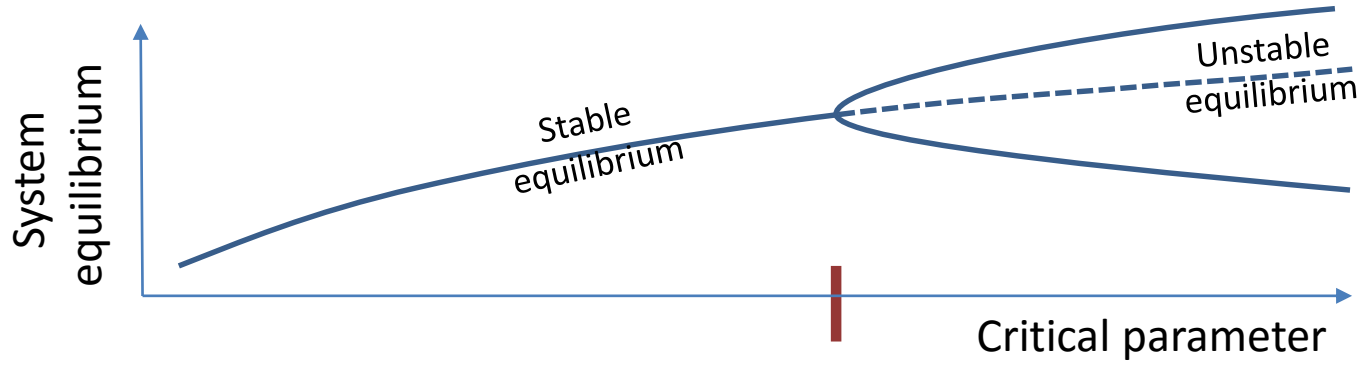
Tipping points:

Formalisations
and model representations

System dynamics: Phase transitions

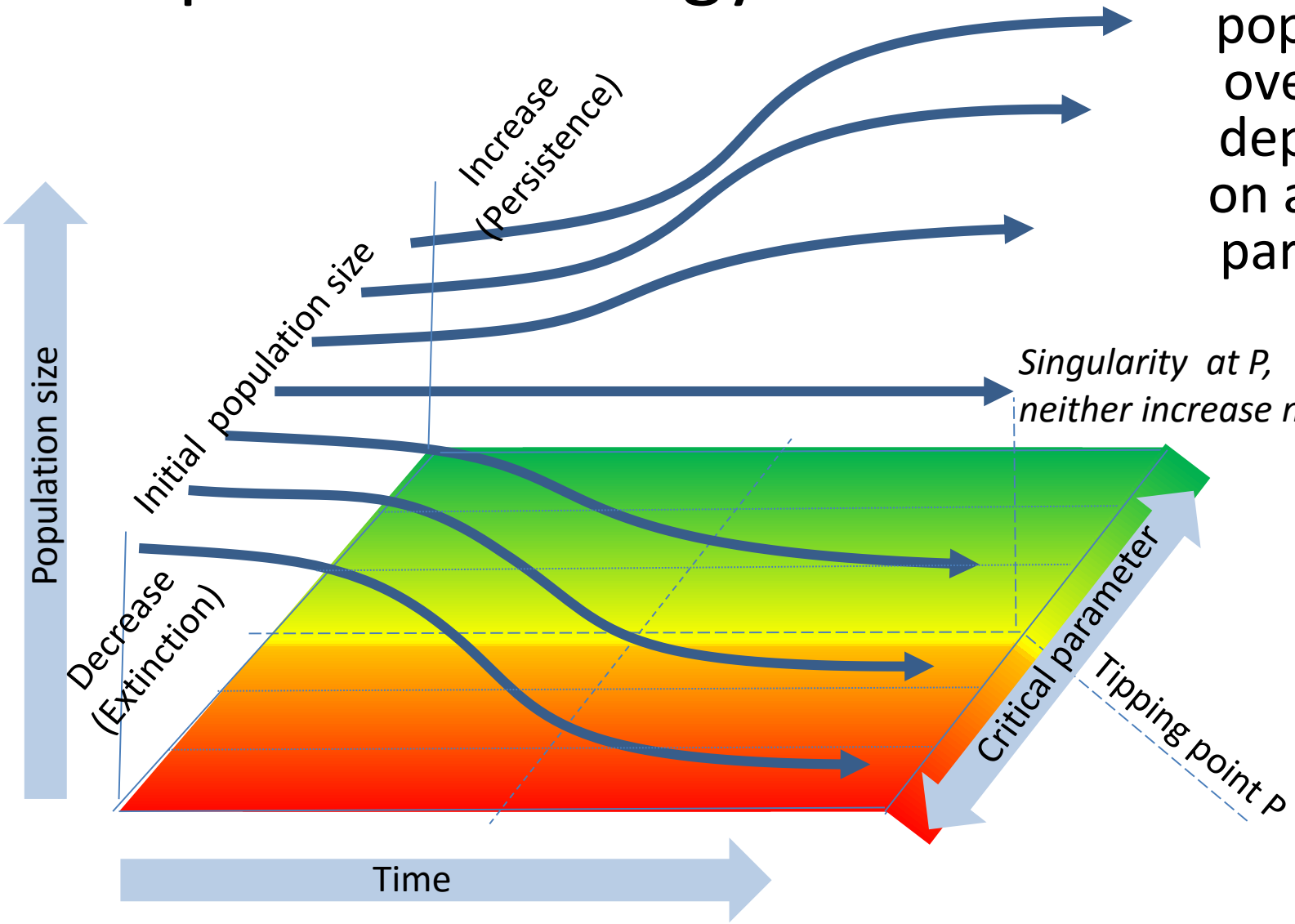
When exceeding a critical threshold of a parameter, new topologically different properties emerge.
Example:

- Bifurcation
  A stable equilibrium becomes unstable and 2 new equilibria emerge



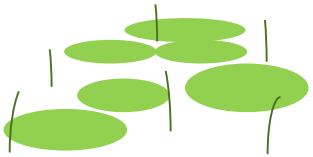
System Dynamics: Population ecology

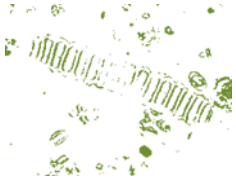
Persistence or extinction of a population over time, depending on a critical parameter



System dynamics:
Hysteresis in ecology: shallow lakes

- In temperate climate, shallow lakes can be dominated by two types of primary producers:
  - Macrophytes or Plankton (micro-)algae

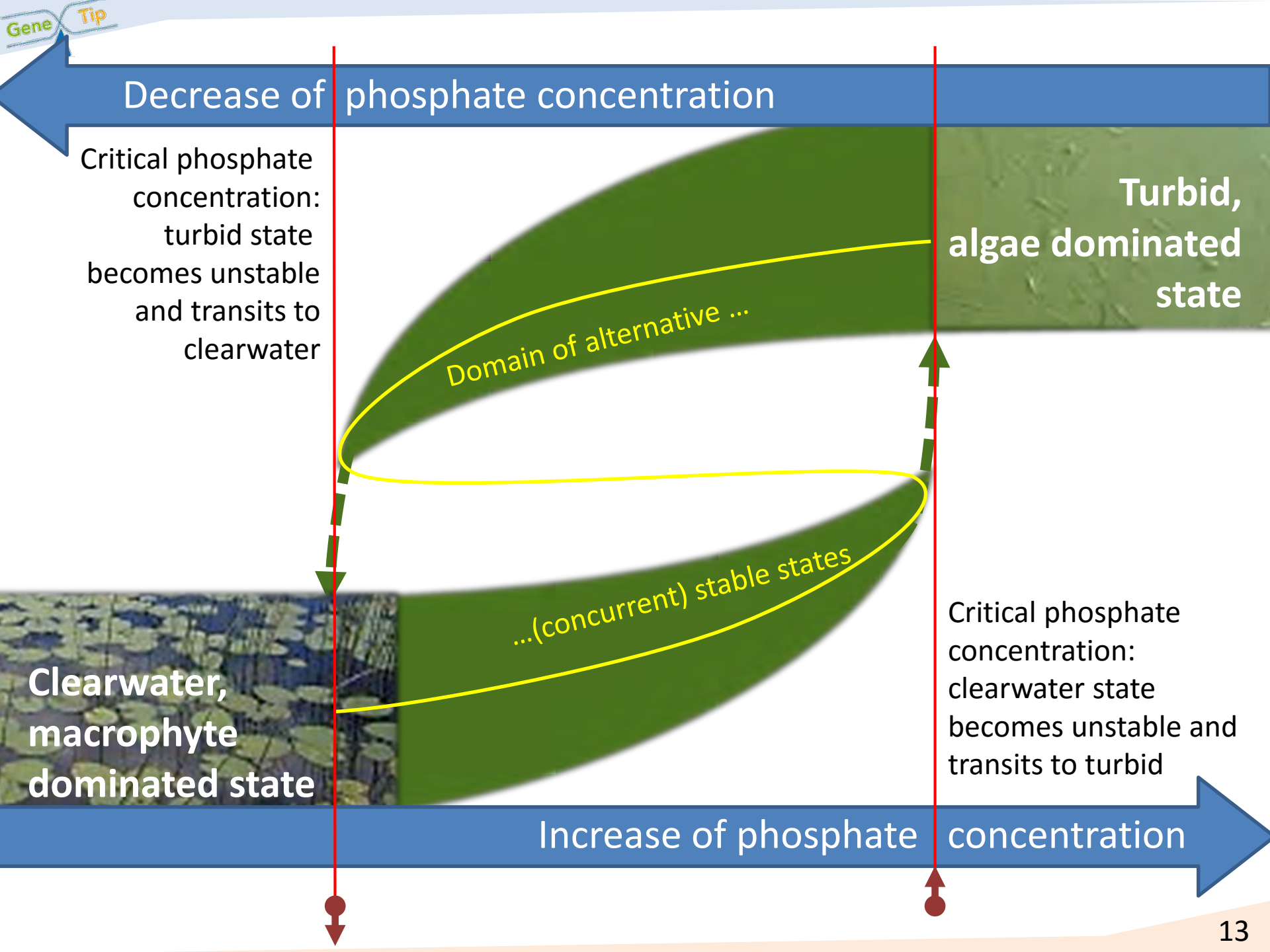




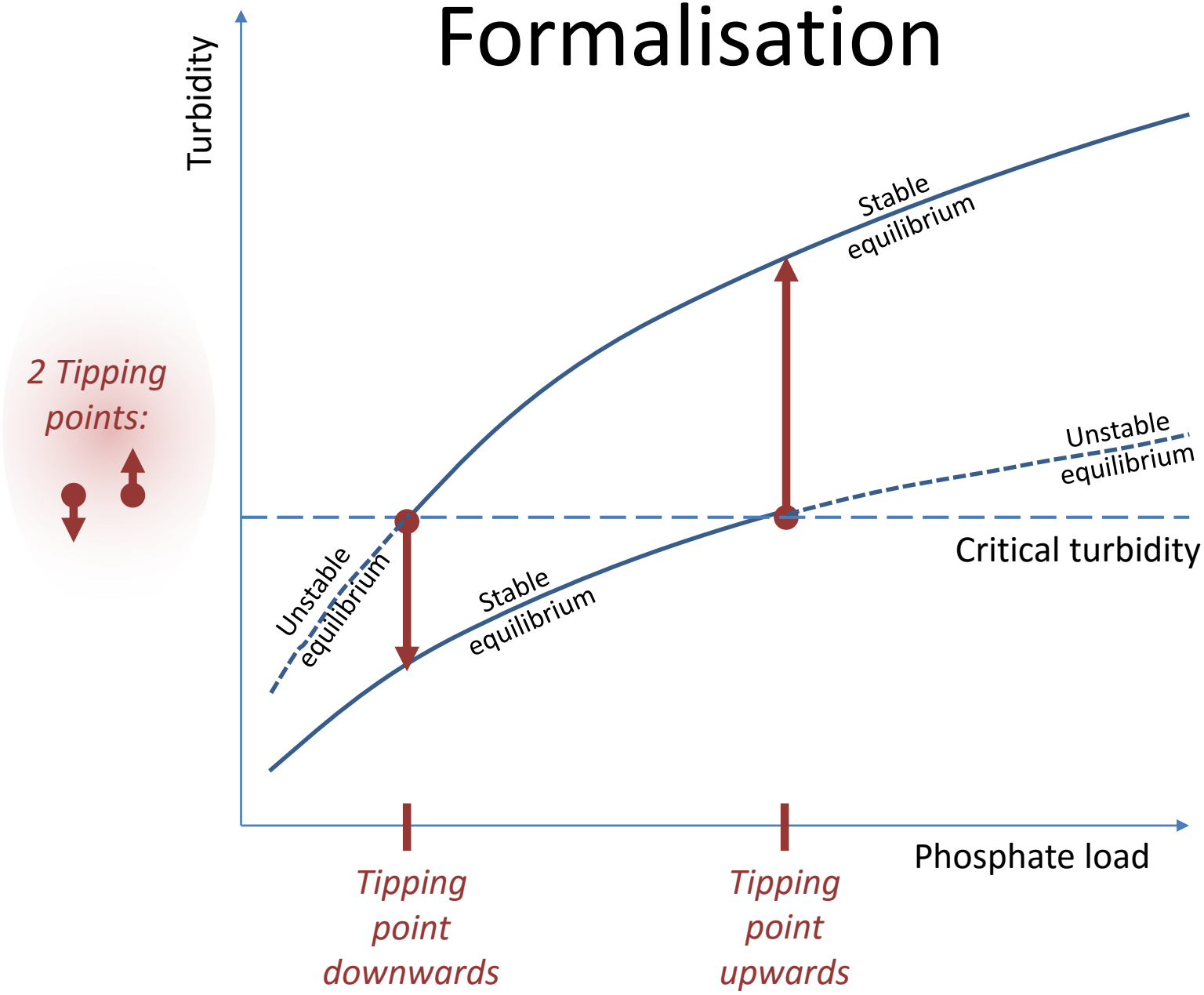
The difference makes the nutrient load (phosphate).

2 tipping points: Shifts between alternative stable states occur at different tipping points depending on increase or decrease of phosphate nutrient concentration.

Scheffer, M., & van Nes, E. H. (2007). Shallow lakes theory revisited: various alternative regimes driven by climate, nutrients, depth and lake size. Hydrobiologia, 584(1), 455-466.


Decrease of phosphate concentration
Critical phosphate concentration: turbid state becomes unstable and transits to clearwater
Turbid, algae dominated state
Domain of alternative …
…(concurrent) stable states
Clearwater, macrophyte dominated state
Critical phosphate concentration: clearwater state becomes unstable and transits to turbid
Increase of phosphate concentration

Formalisation



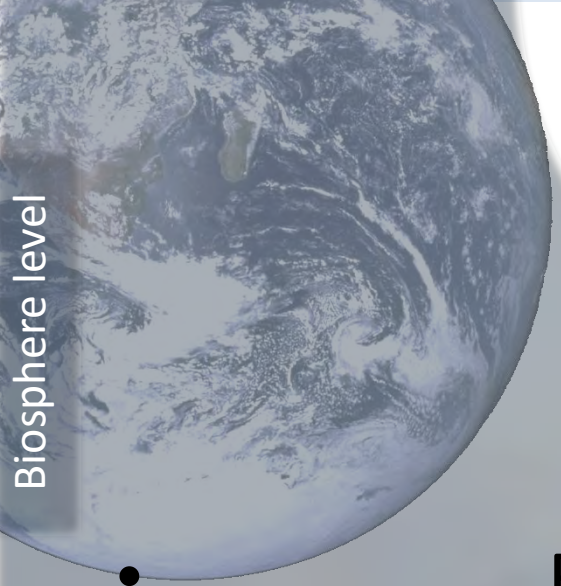
Discussion of

gene drive related tipping points

Determination of tipping points depends on the considered context

- Gene drive related tipping points can refer to
  - Technological thresholds
    - Power, range, correctability breakthrough
  - Ecological thresholds
    - Referring to population dynamics, ecosystem and landscape context
  - Agronomy and ecosystem management
    - Critical points in the organisation of human intervention and feedback from natural systems
  - Economic tipping points
    - Power, affordability and coexistence breakthrough

Hierarchy of biological self-organisation levels



Level	Relevant processes
Biosphere	self-regulation
Biomes	cross-regional shifts
Landscapes	pattern dynamics
Ecosystems	nutrient circulation
Populations	trophic relations
Organisms	organisation
Cells	interaction
Molecules	catalysis

Expanding Power and Range beyond

Gene drive tipping point discussion

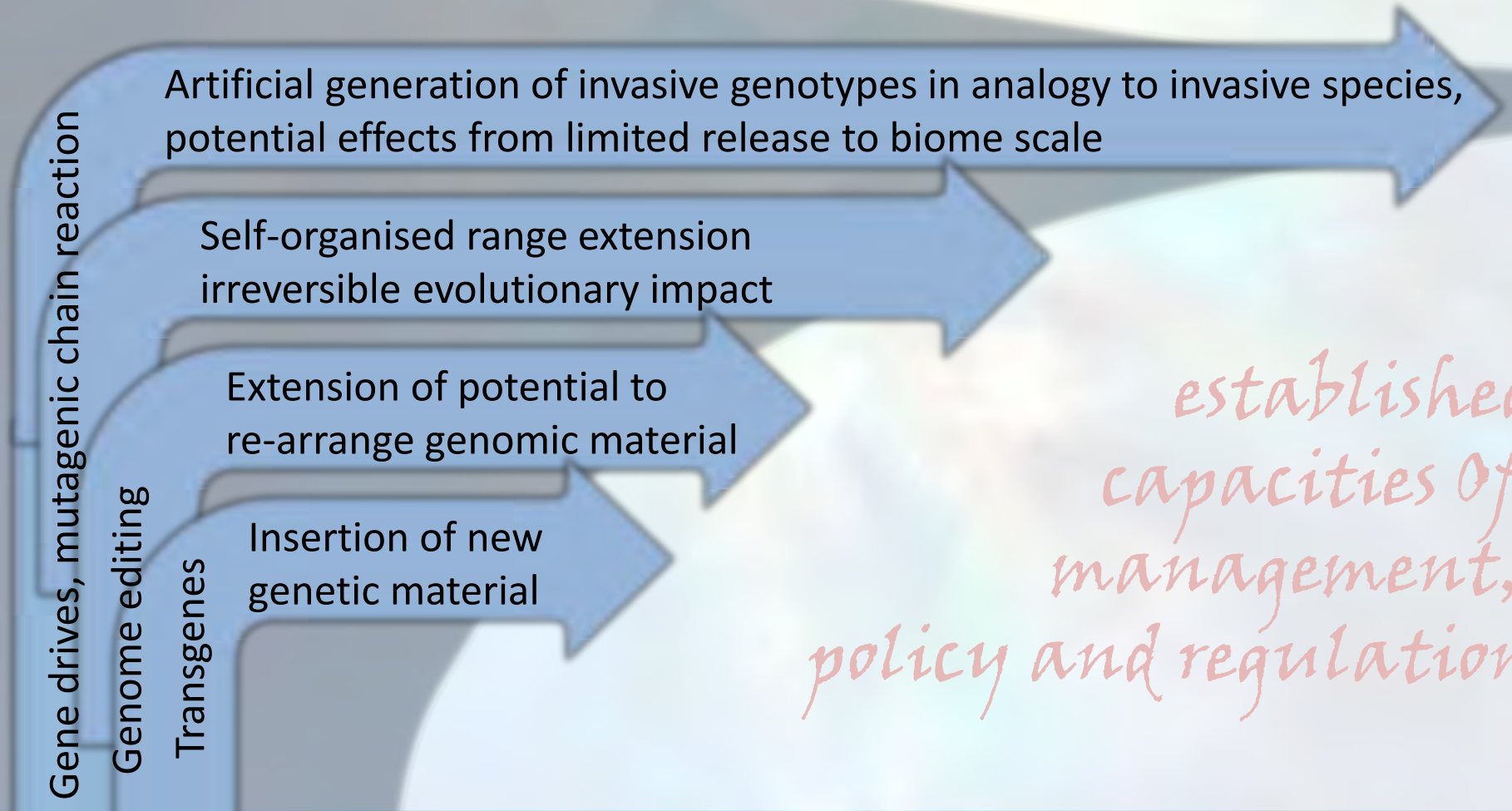
- **Biological / physiological**

established capacities of management, policy and regulation

Expanding Power and Range Beyond

Gene drive tipping point discussion

- **Ecological**



established capacities of management, policy and regulation

Expanding Power and Range beyond

Gene drive tipping point discussion

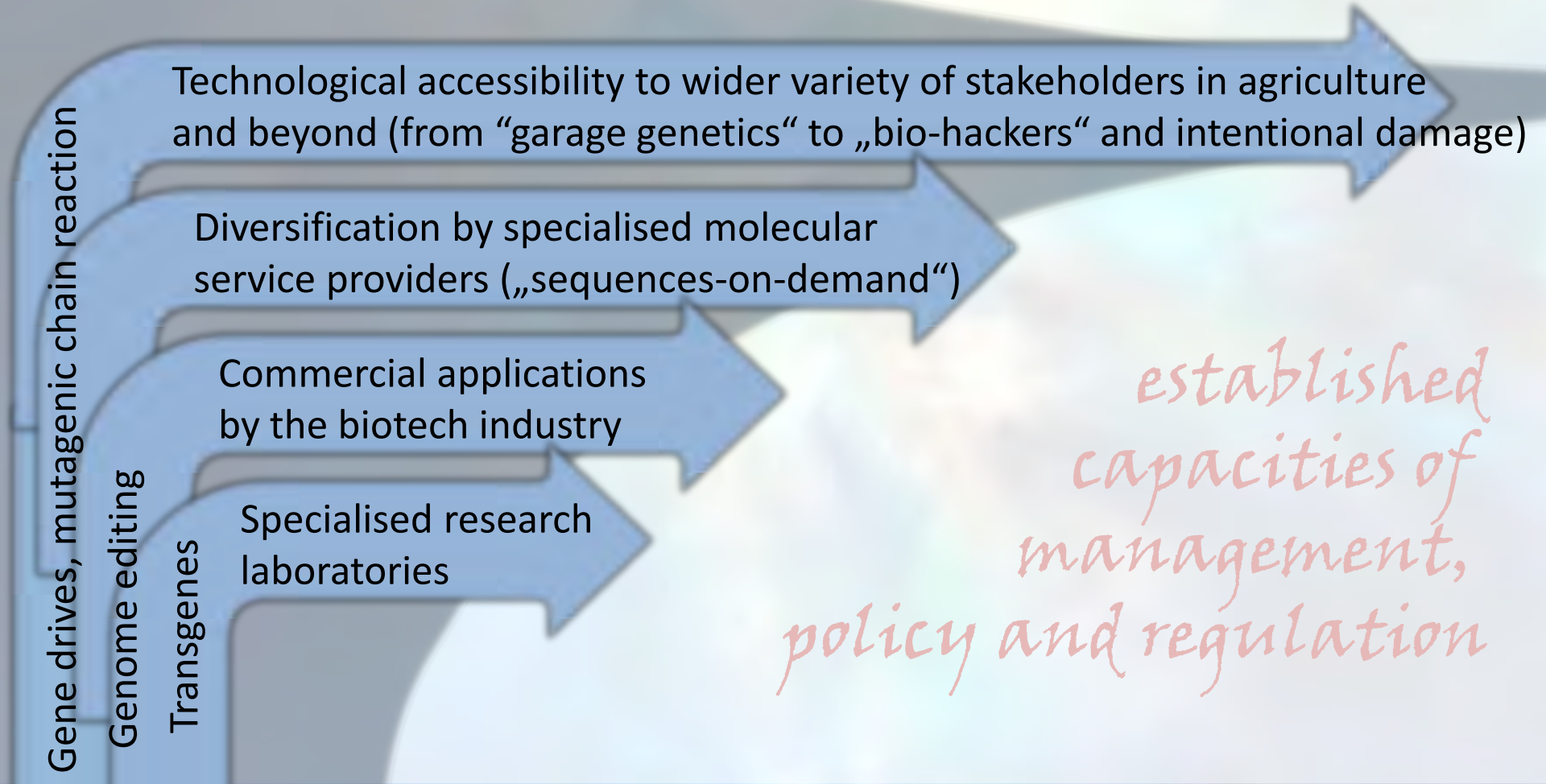
- **Economic Transitions**

established capacities of management, policy and regulation

Expanding Power and Range beyond

Gene drive tipping point discussion

- **Biosafety conditions, survey requirements**



Gene drives touch different tipping points

- Plant and animal population dynamics
- Environmental and ecological interactions ecosystem and landscape processes
- Social ecological interactions ecosystem management, best practice
- Economic transitions
- Ethical and regulatory (legal) implications

Interdisciplinary expertise is required for assessment

Gene drives touch different tipping points

- Combined interdisciplinary expertise is required for assessment

- To identify, relate, valuate possible tipping points on different levels of organisation, in particular
  - Ecological tipping points,
    e.g. extinctions, invasions, system transitions
  - Technological tipping points
    e.g. power, range, correctability
  - Social / regulatory tipping points
    e.g. efficiency, enforcement criteria

- To acquire knowledge to determine measures to avoid unintended, undesirable dynamics or diminish their effects

Thank you for your attention