How do we define and measure ecosystem resilience in savannas?

Mariska te Beest, Corli Coetsee, Joris Cromsigt

With ongoing global change, understanding the resilience of ecosystems is increasingly important.

But how do we measure resilience in real ecosystems?

nature › communications earth & environment › comment › article

Comment | Open access | Published: 14 February 2025

Make African grasslands climate-change resilient

Tersur T. Akpensuen, Andrew D. Cartmill, Simón Pérez-Márquez, Helen Sheridan, Michael R. F. Lee & M

Jordana Rivero

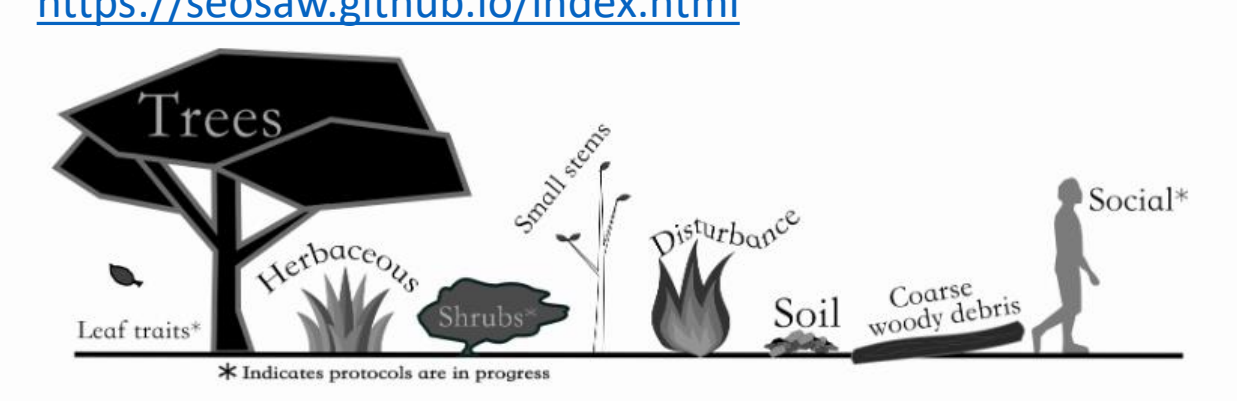
Communications Earth & Environment **6**, Article number: 111 (2025) | Cite this article

Using long-term tree inventories to determine savanna resilience

SEOSAW

A Socio-Ecological Observatory for Studying African Woodlands

https://seosaw.github.io/index.html



RESILIENCE
ERC SYNERGY

https://ercsynergy-resilience.eu/

Casey Ryan
Penny Mograbi
Sally Archibald
& many others

Max Rietkerk
Neha Mohan Babu
Fezile Mtsetfwa
Marina Khoza

Defining resilience

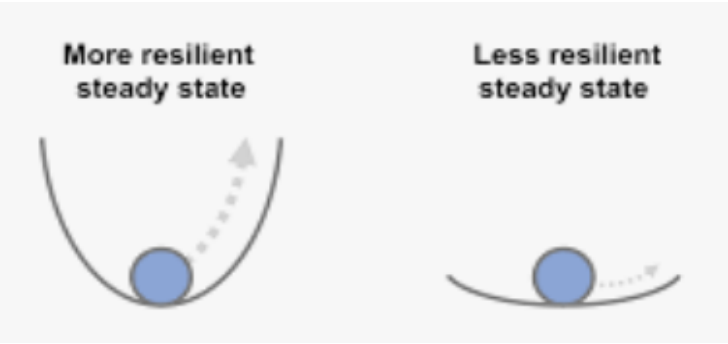
- **Resilience:**

  (1) the capacity to withstand or to recover quickly from difficulties; toughness;

  (2) the ability of a substance or object to spring back into shape; elasticity.

- Holling (1973) introduced the concept and defines resilience as **the ability of a system to withstand perturbations without shifting to a different state**

- In ecology, resilience often refers to **the ability of a system to cope with disturbances, bounce back, and maintain its state and functionality** (Dakos and Kefi 2022)**, by either resisting change and/or recovering after the stress** (Irob et al. 2023).



Ball-in-cup or ball-and-valley model
https://en.wikipedia.org/wiki/Resilience_(mathematics)

Holling CS (1973). Resilience and stability of ecological systems. *Annl Rev Ecol Syst* 4:1-23
Dakos V & S Kéfi (2022). "Ecological resilience: what to measure and how. *Environ Res Lett* 17: 043003
Irob K et al. (2023). Savanna resilience to droughts increases with the proportion of browsing wild herbivores and plant functional diversity. J Appl Ecol 60(2): 251-262.

Ecological resilience: from theory to practice

- However, moving from the intuitive understanding of the concept of resilience to practically measuring resilience has been a real challenge in ecology (Gunderson 2000, Carpenter et al. 2001, Dakos and Kefi 2022)

→ Well-understood theoretically, less so in practice

Gunderson, L. H. (2000). Ecological resilience—in theory and application. Ann Rev Ecol Syst 31(1): 425-439.
Carpenter, S., et al. (2001). From metaphor to measurement: resilience of what to what? Ecosystems 4: 765-781.
Dakos V & S Kéfi (2022). Ecological resilience: what to measure and how. *Environ Res Lett* 17: 043003

Resilience definition evolved over time

- From studying the local stability of a single system, to the idea that a system may exhibit different states when perturbed (Dakos and Kefi, 2022; Irob et al. 2023)
- Two main definitions:
  - **engineering resilience**: recovery rate of a system after a disturbance

Engineering resilience – clear metrics (i.e. loss of functional redundancy and/or loss of keystone species)

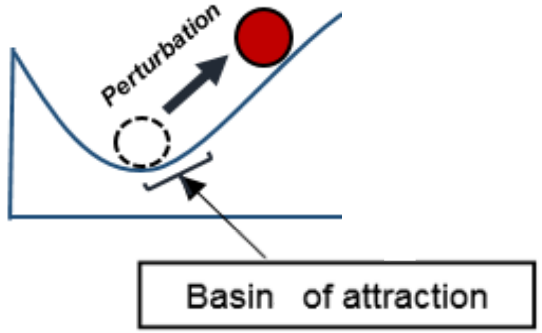


Figure of ball-in-cup model adapted from https://passel2.unl.edu/view/lesson/d6c3e24cbc7e/3 (Original by Alison Ludwig)

Dakos V & S Kéfi (2022). Ecological resilience: what to measure and how. *Environ Res Lett* 17: 043003

Irob K et al. (2023). Savanna resilience to droughts increases with the proportion of browsing wild herbivores and plant functional diversity. J Appl Ecol 60(2): 251-262.

Resilience definition evolved over time

- From studying the local stability of a single system, to the idea that a system may exhibit different states when perturbed (Dakos and Kefi, 2022; Irob et al. 2023)
- Two main definitions:
  - **engineering resilience**: recovery rate of a system after a disturbance
  - **ecological resilience**: the magnitude of disturbance that can be absorbed before a system flips to another state

Engineering resilience – clear metrics (i.e. loss of functional redundancy and/or loss of keystone species)

Ecological resilience – remains elusive

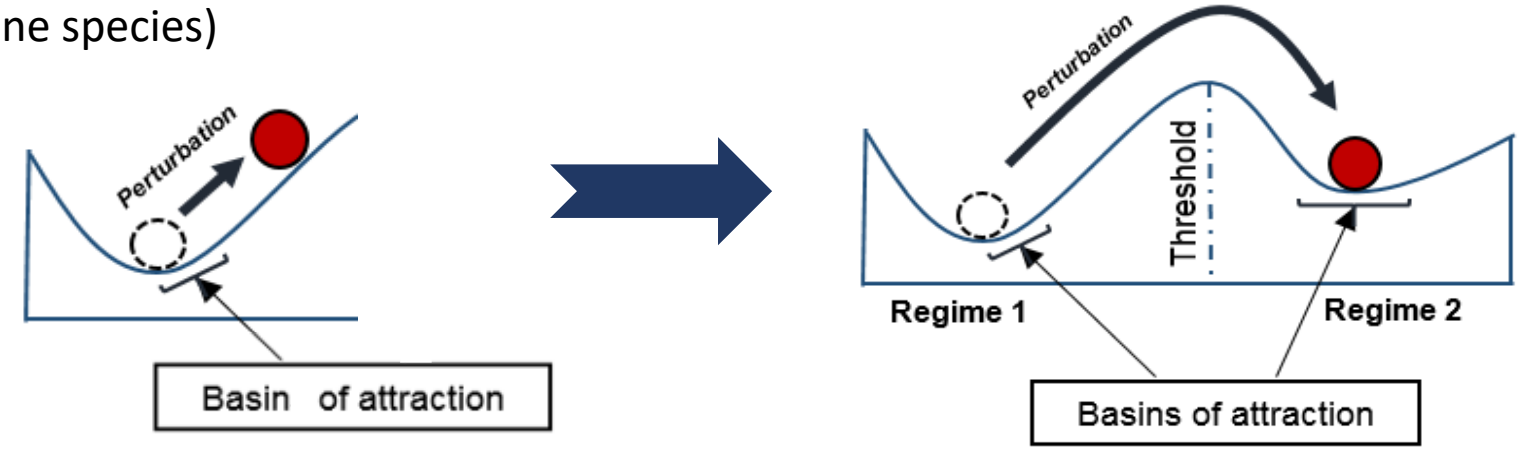


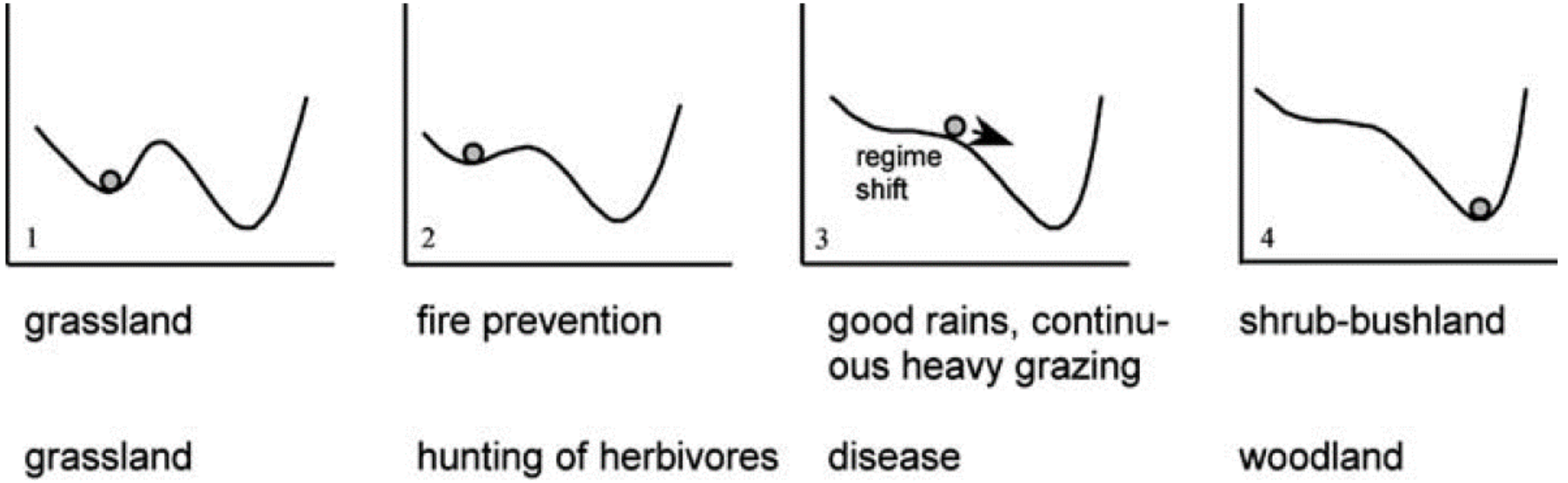
Figure of ball-in-cup model adapted from https://passel2.unl.edu/view/lesson/d6c3e24cbc7e/3 (Original by Alison Ludwig)

Dakos V & S Kéfi (2022). Ecological resilience: what to measure and how. *Environ Res Lett* 17: 043003

Irob K et al. (2023). Savanna resilience to droughts increases with the proportion of browsing wild herbivores and plant functional diversity. J Appl Ecol 60(2): 251-262.

Savanna resilience

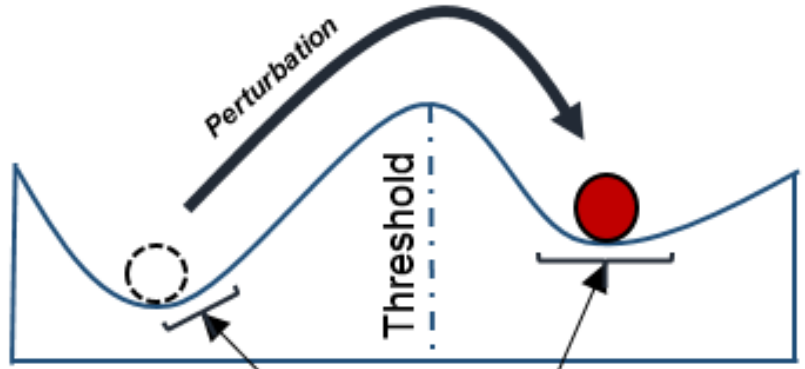
Some of the earlier work on the resilience of savanna ecosystems conducted by Brian Walker and colleagues focused on tree-grass ratios



Walker BH & I Noy-Meir (1982). Aspects of the Stability and Resilience of Savanna Ecosystems. In: *Ecology of Tropical Savanna*. Huntley and Walker (eds). Springer Berlin Heidelberg.
Folke C et al. (2004). Regime shifts, resilience, and biodiversity in ecosystem management. *Ann Rev Ecol Evol Syst* 35: 557-581.
Walker B et al. (2004). Resilience, adaptability and transformability in social–ecological systems. *Ecol Soc* 9(2)

Savanna resilience

- Traditionally a strong focus on structural parameters: tree-grass ratios and tree cover

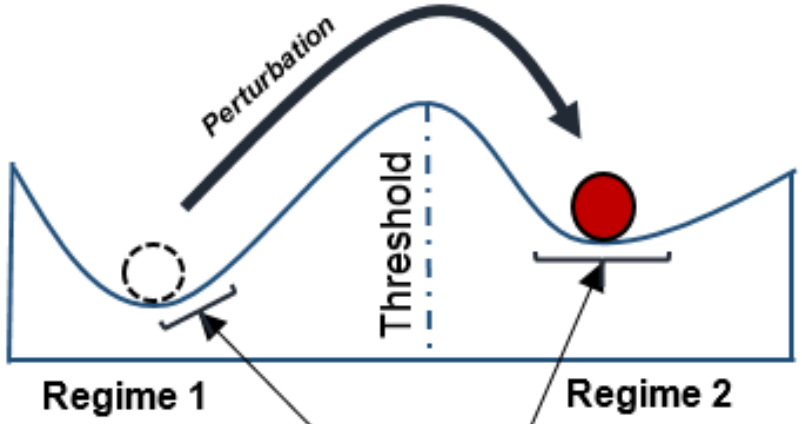


Open state

Closed state

Figure of ball-in-cup model adapted from https://passel2.unl.edu/view/lesson/d6c3e24cbc7e/3 (Original by Alison Ludwig)

But savannas are highly variable in tree cover, so how to define alternative states?



Basins of attraction

?

Open state

Closed state

Forest

Inherent plasticity of savannas

Figure of ball-in-cup model adapted from https://passel2.unl.edu/view/lesson/d6c3e24cbc7e/3 (Original by Alison Ludwig)

Mesic conditions

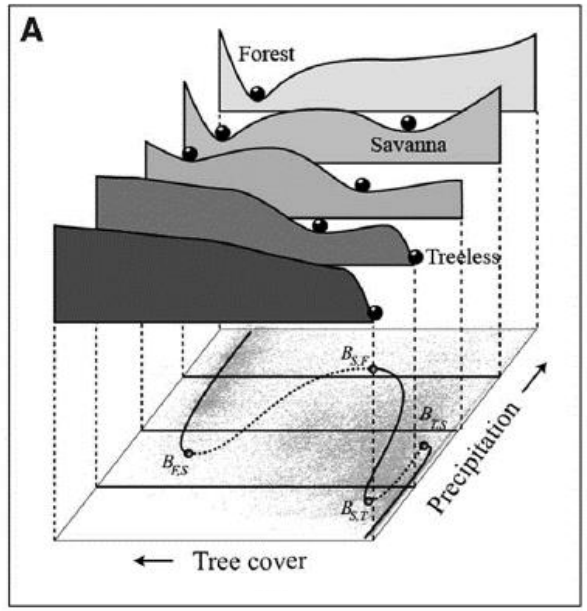
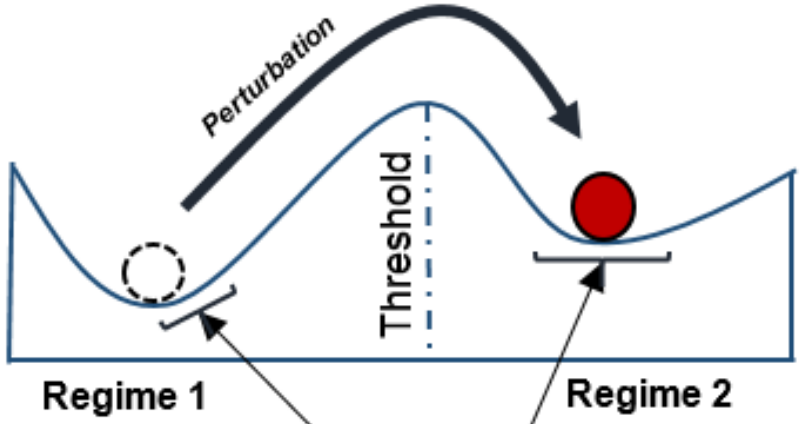


Fig. 3. Relationship between the resilience of tropical forest, savanna, and treeless states and mean annual precipitation (in millimeters per year). (**A**)

Hirota et al. 2011 Science

But savannas are highly variable in tree cover, so how to define alternative states?



Basins of attraction

?

Open state

Closed state

Desert

Inherent plasticity of savannas

Arid conditions

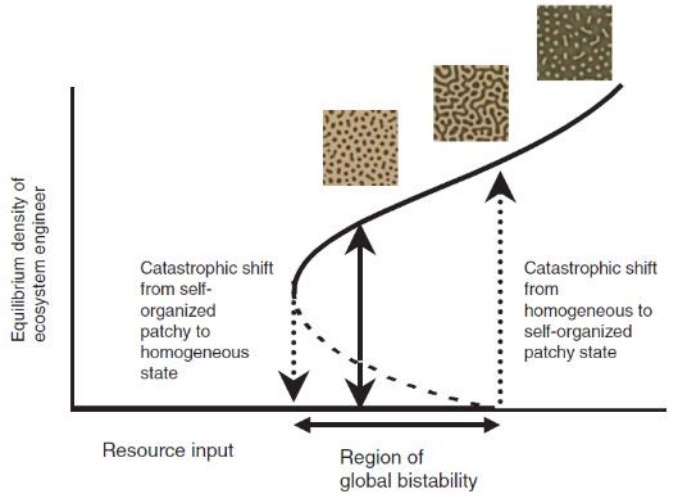


Fig. 3. Model showing how ecosystems may undergo a predictable sequence of emerging self-organized patchiness as resource input decreases or increases (*11, 12, 14,*

Figure of ball-in-cup model adapted from https://passel2.unl.edu/view/lesson/d6c3e24cbc7e/3 (Original by Alison Ludwig)

Rietkerk et al. 2004 Science

Also, wouldn’t this variability in tree cover make savannas inherently more resilient to change?

How is this affected by the distribution or spatial configuration of these states across the landscape?

How to distinguish forest – savanna – grassland mosaics…

Hluhluwe-iMfolozi Park, South Africa

… from open vs closed savanna mosaics?

Hluhluwe-iMfolozi Park, South Africa

Structural parameters alone not enough to determine resilience, need to include compositional parameters and variability in space across landscapes

Hluhluwe-iMfolozi Park, South Africa

Hluhluwe-iMolozi Park

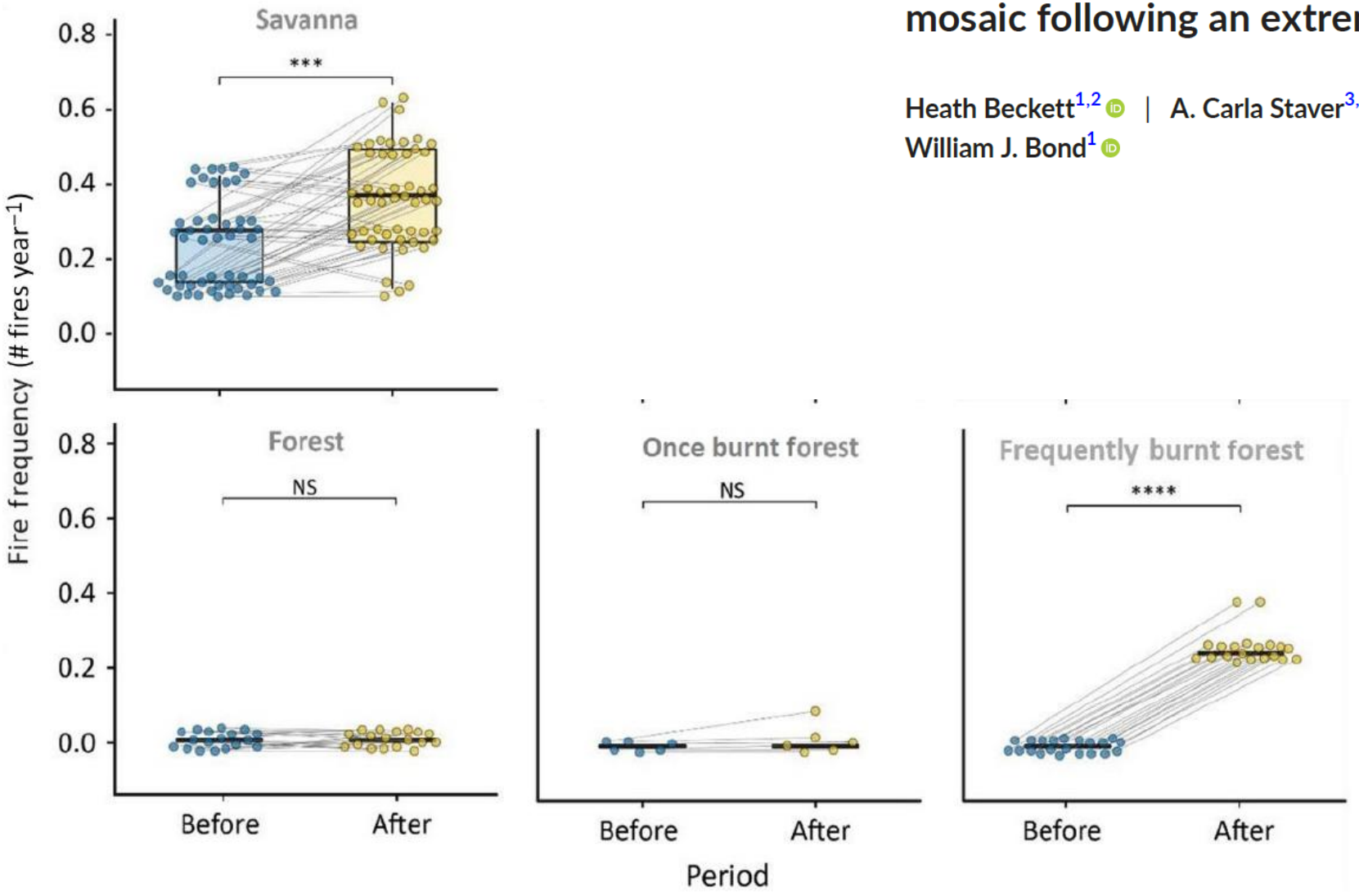
DOI: 10.1111/1365-2745.13851

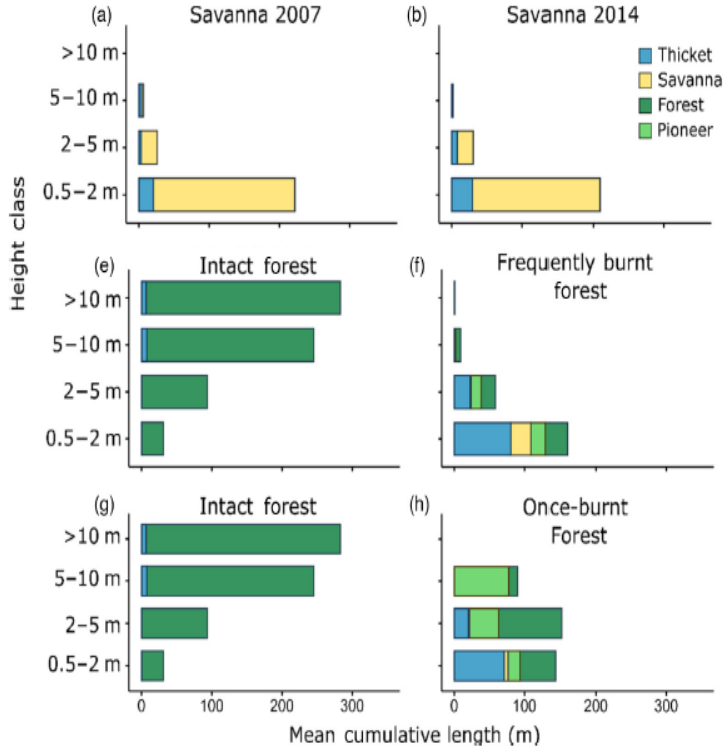
RESEARCH ARTICLE

Journal of Ecology | BRITISH ECOLOGICAL SOCIETY

Pathways of savannization in a mesic African savanna–forest mosaic following an extreme fire

Heath Beckett[1,2] | A. Carla Staver[3,4] | Tristan Charles-Dominique[5] | William J. Bond[1]





Many open questions remain – input welcome ☺

- If and how can resilience theory be applied to savannas?
- Need a focus on both structural and compositional indicators along environmental gradients or stressors.
- What indicators could we use to define and measure savanna resilience?
  - Species and functional diversity across taxa
  - Functional redundancy
  - Tree mortality/loss of tall trees
  - Spatial patterning
  - Recovery rates

Received: 1 July 2022 | Accepted: 14 December 2022
DOI: 10.1111/1365-2664.14351

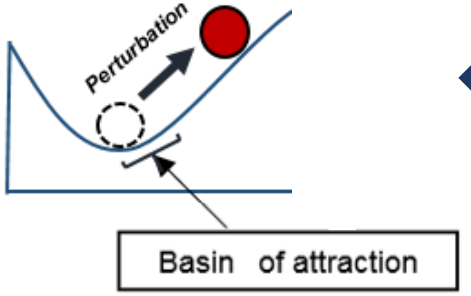
Journal of Applied Ecology

RESEARCH ARTICLE

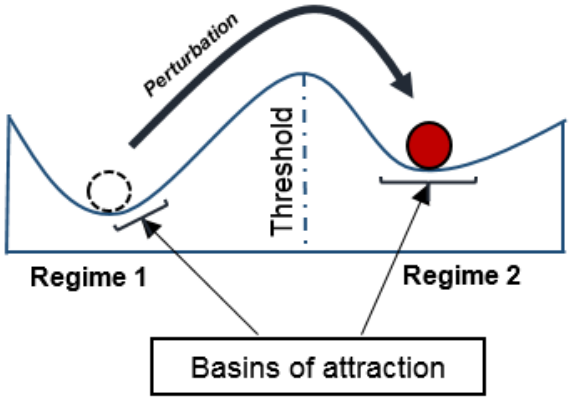
Savanna resilience to droughts increases with the proportion of browsing wild herbivores and plant functional diversity

Katja Irob[1] | Niels Blaum[2] | Alex Weiss-Aparicio[1] | Morgan Hauptfleisch[3] | Robert Hering[2] | Kenneth Uiseb[4] | Britta Tietjen[1,5]

Engineering (ecosystem) resilience



Ecological resilience



Thank you for listening

Wilding grasslands

- Focused on creating socio-ecological resilience
- Developing natural climate solutions that benefit local likelihoods
- Study site: Umzimvubu catchment, Matatiele, Eastern Cape, South Africa
- 4 postdocs to be advertised – 2 social science, 2 natural science

Simba LD et al. (2024). Wilder rangelands as a natural climate opportunity: Linking climate action to biodiversity conservation and social transformation. Ambio: 1-19

https://wilderrangelands.org/