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Environmental Research Letters

TOPICAL REVIEW

Defining tipping points for social-ecological systems scholarship—an interdisciplinary literature review

Manjana Milkoreit[1], Jennifer Hodbod[2,11], Jacopo Baggio[3], Karina Benessaiah[4], Rafael Calderón-Contreras[5], Jonathan F Donges[6,7], Jean-Denis Mathias[8], Juan Carlos Rocha[7], Michael Schoon[9] and Saskia E Werners[10]

Questions

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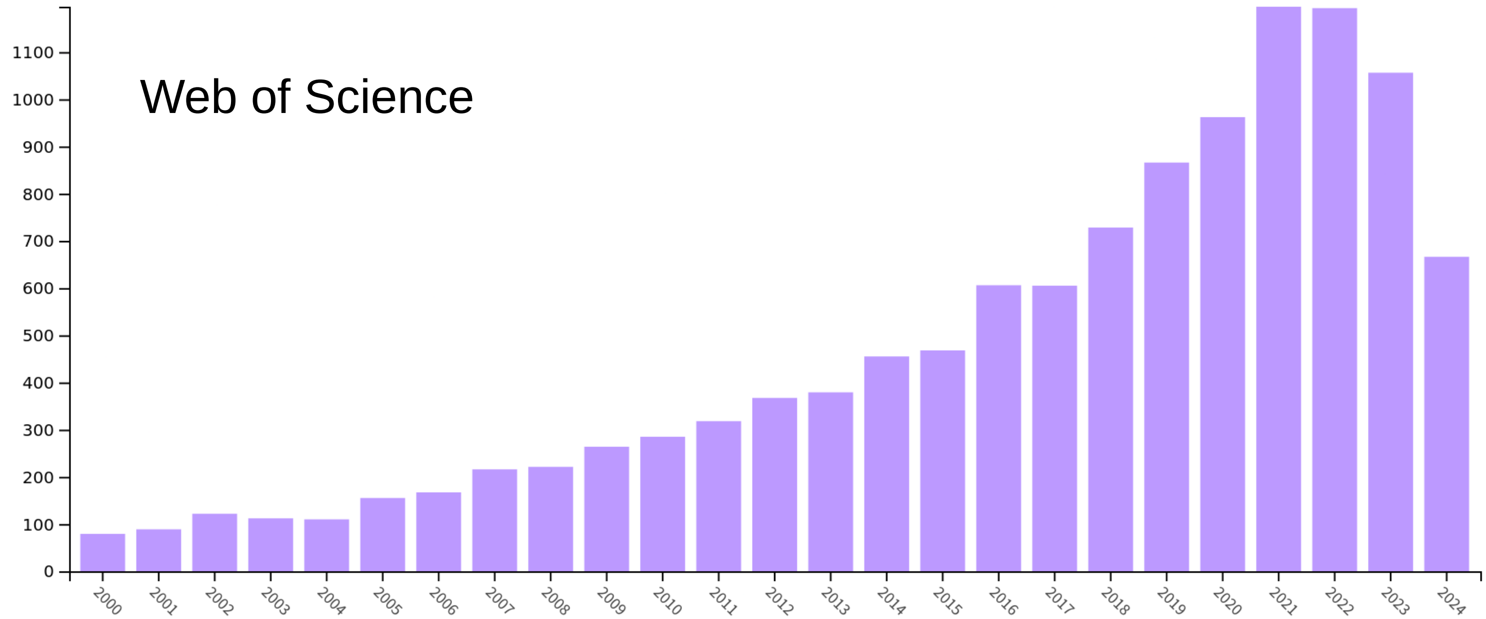
   If we are to disagree with this*, must we also disagree with resilience and stability, too?
4) Does this* translate to social systems?

* “This” is the whole tangle of terms

My [early] take on

“alternative stable states” /
“critical transitions” /
“thresholds” /
“tipping points” /
“regime shifts” /
“abrupt changes”

in Ecology



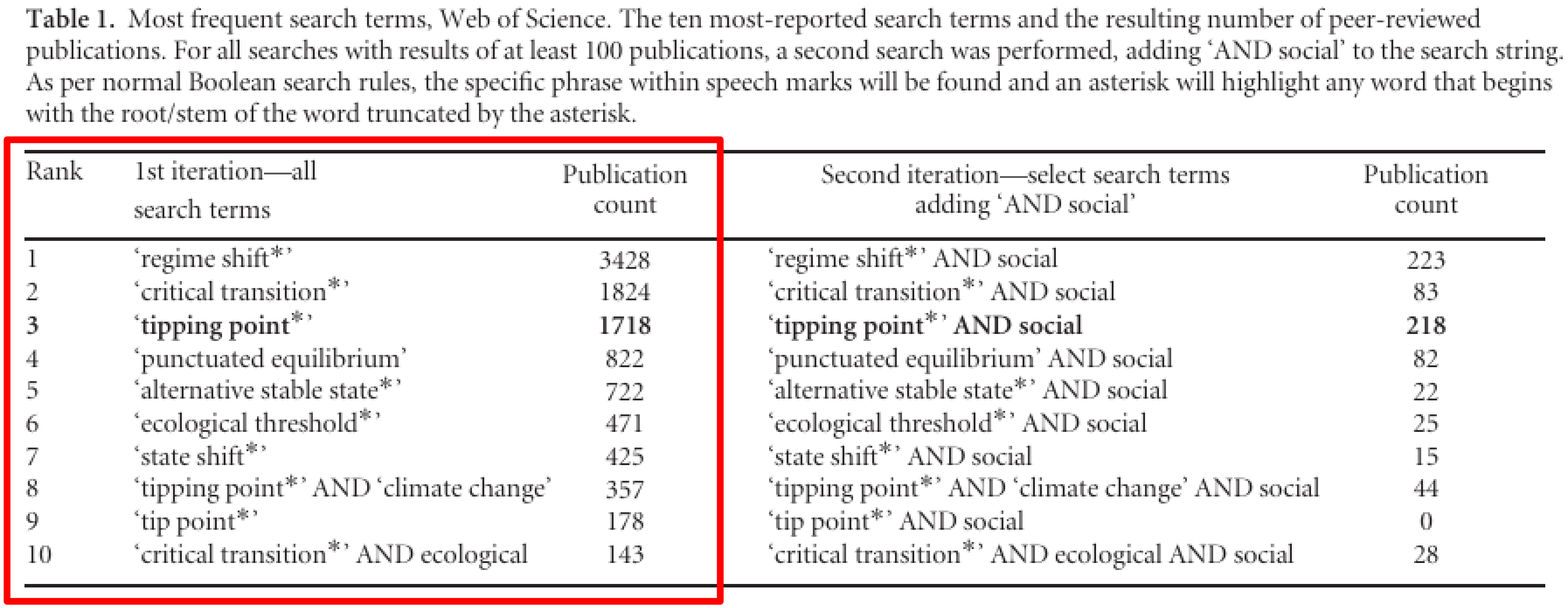


Table 1. Most frequent search terms, Web of Science. The ten most-reported search terms and the resulting number of peer-reviewed publications. For all searches with results of at least 100 publications, a second search was performed, adding 'AND social' to the search string. As per normal Boolean search rules, the specific phrase within speech marks will be found and an asterisk will highlight any word that begins with the root/stem of the word truncated by the asterisk.

Rank	1st iteration—all search terms	Publication count	Second iteration—select search terms adding 'AND social'	Publication count
1	'regime shift*'	3428	'regime shift*' AND social	223
2	'critical transition*'	1824	'critical transition*' AND social	83
3	**'tipping point*'**	**1718**	**'tipping point*' AND social**	**218**
4	'punctuated equilibrium'	822	'punctuated equilibrium' AND social	82
5	'alternative stable state*'	722	'alternative stable state*' AND social	22
6	'ecological threshold*'	471	'ecological threshold*' AND social	25
7	'state shift*'	425	'state shift*' AND social	15
8	'tipping point*' AND 'climate change'	357	'tipping point*' AND 'climate change' AND social	44
9	'tip point*'	178	'tip point*' AND social	0
10	'critical transition*' AND ecological	143	'critical transition*' AND ecological AND social	28

Milkoreit *et al* 2018 *Environ. Res. Lett.* **13** 033005

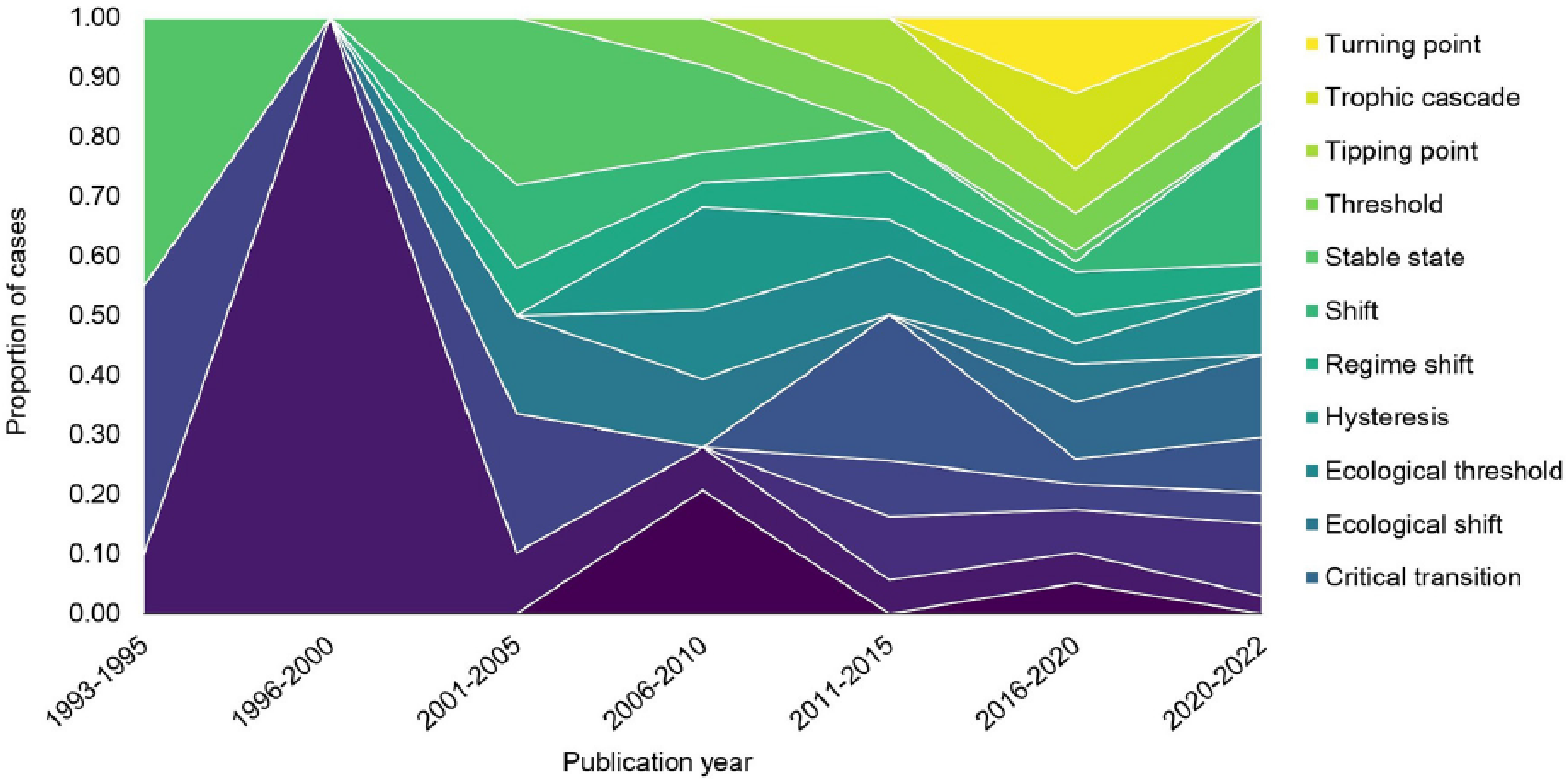


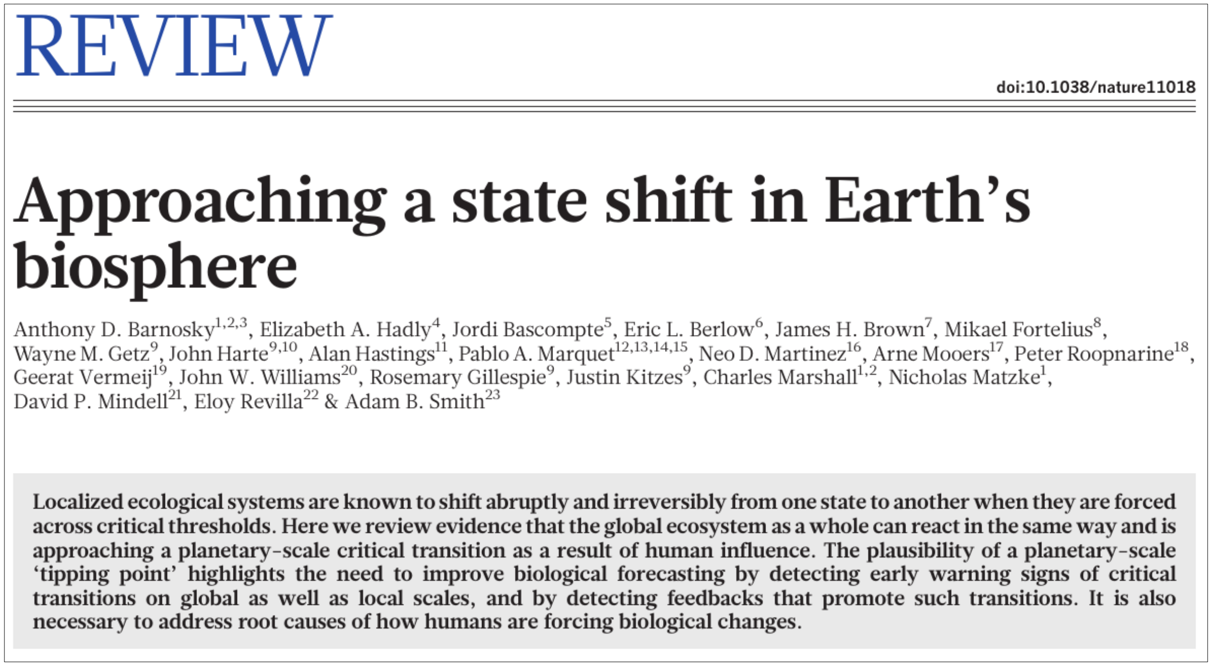
FIGURE 3
Change in author terminology for tipping point literature through time. The proportion of cases was determined from the total number of cases per five-year publication increment. Note that 1993-1995 and 2020-2022 are partial increments due to data availability. Only author terminology used five or more times in the database (i.e., ≥1% of all cases each) was considered.

Hernández Martínez de la Riva A, Harper M, Rytwinski T, Sahdra A, Taylor JJ, Bard B, Bennett JR, Burton D, Creed IF, Haniford LSE, Hanna DE, Harmsen EJ, Robichaud CD, Smol JP, Thapar M and Cooke SJ (2023) Tipping points in freshwater ecosystems: an evidence map. *Front. Freshw. Sci.* 1:1264427. doi: 10.3389/ffwsc.2023.1264427

I want to know:

- Is the theory solid?
  - in its quantitative details
  - in its broad, verbal use
- How does the evidence stack up?
  - in its components – for consistency with theory
  - across spatiotemporal scales – for generality

We will not be the first



REVIEW

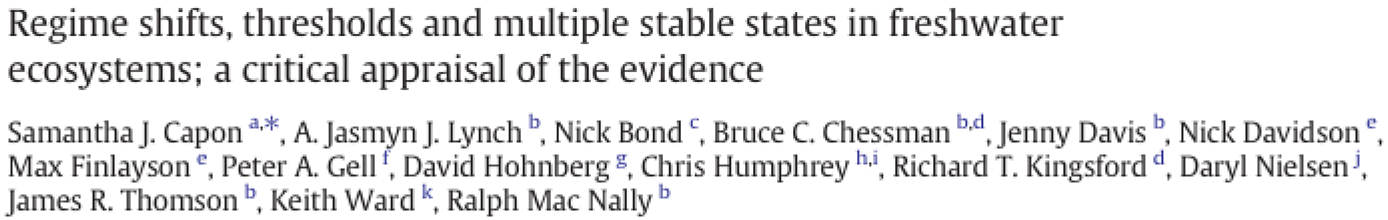
doi:10.1038/nature11018

Approaching a state shift in Earth's biosphere

Anthony D. Barnosky[1,2,3], Elizabeth A. Hadly[4], Jordi Bascompte[5], Eric L. Berlow[6], James H. Brown[7], Mikael Fortelius[8], Wayne M. Getz[9], John Harte[9,10], Alan Hastings[11], Pablo A. Marquet[12,13,14,15], Neo D. Martinez[16], Arne Mooers[17], Peter Roopnarine[18], Geerat Vermeij[19], John W. Williams[20], Rosemary Gillespie[9], Justin Kitzes[9], Charles Marshall[1,2], Nicholas Matzke[1], David P. Mindell[21], Eloy Revilla[22] & Adam B. Smith[23]

Localized ecological systems are known to shift abruptly and irreversibly from one state to another when they are forced across critical thresholds. Here we review evidence that the global ecosystem as a whole can react in the same way and is approaching a planetary-scale critical transition as a result of human influence. The plausibility of a planetary-scale 'tipping point' highlights the need to improve biological forecasting by detecting early warning signs of critical transitions on global as well as local scales, and by detecting feedbacks that promote such transitions. It is also necessary to address root causes of how humans are forcing biological changes.

2012



Regime shifts, thresholds and multiple stable states in freshwater ecosystems; a critical appraisal of the evidence

Samantha J. Capon[a,*], A. Jasmyn J. Lynch[b], Nick Bond[c], Bruce C. Chessman[b,d], Jenny Davis[b], Nick Davidson[e], Max Finlayson[e], Peter A. Gell[f], David Hohnberg[g], Chris Humphrey[h,i], Richard T. Kingsford[d], Daryl Nielsen[j], James R. Thomson[b], Keith Ward[k], Ralph Mac Nally[b]

2015

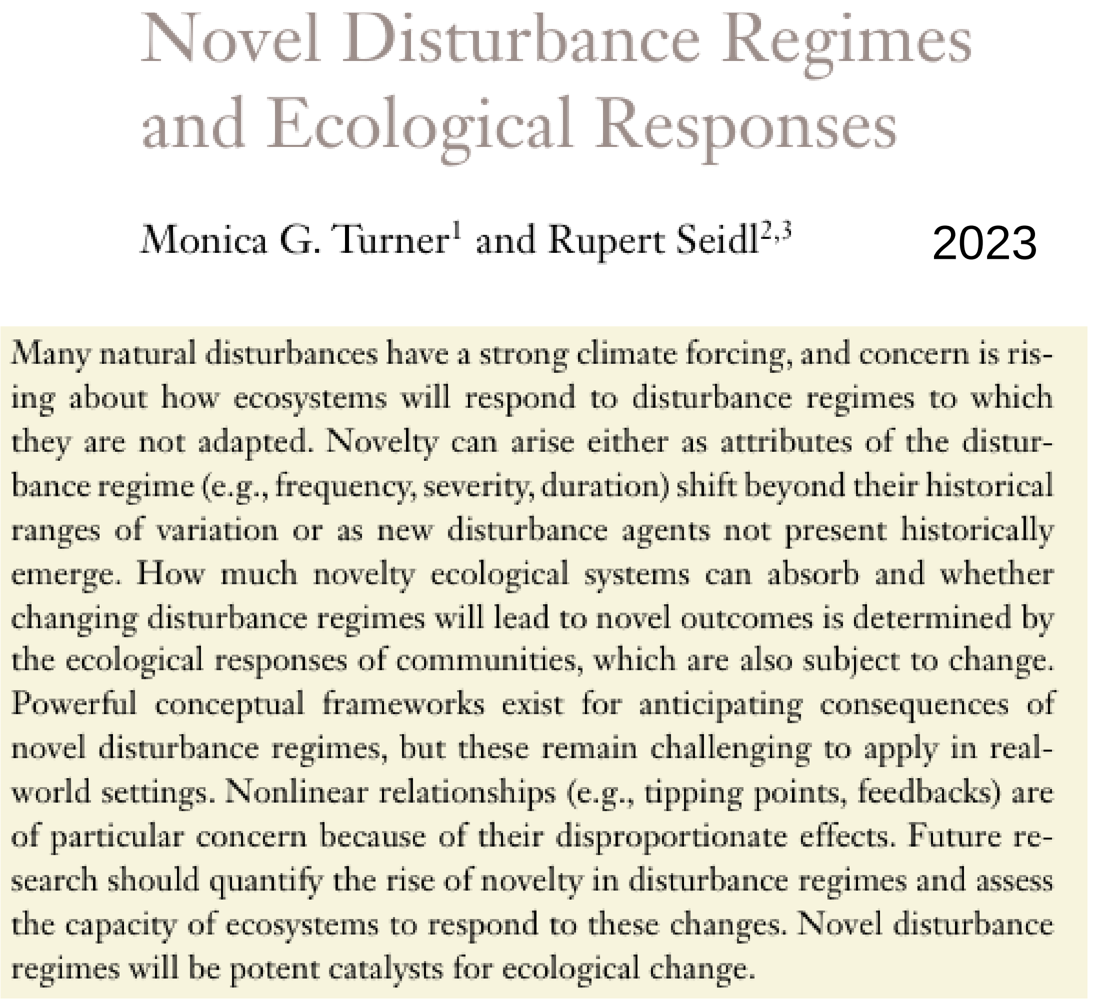
"We found limited understanding of the subtleties of the relevant theoretical concepts and encountered few mechanistic studies that investigated or identified cause-and-effect relationships between ecological responses and nominal pressures. … although the concepts of regime shifts and alternative stable states have become prominent in the scientific and management literature, their empirical underpinning is weak outside of a specific environmental setting. The application of these concepts in future research and management applications should include evidence on the mechanistic links between pressures and consequent ecological change. Explicit consideration should also be given to whether observed temporal dynamics represent variation along a continuum rather than categorically different states."

Planetary Boundaries for Biodiversity: Implausible Science, Pernicious Policies

José M. Montoya,[1,*]
Ian Donohue,[2] and
Stuart L. Pimm[3]

2018

The notion of a 'safe operating space for biodiversity' is vague and encourages harmful policies. Attempts to fix it strip it of all meaningful content. Ecology is rapidly gaining insights into the connections between biodiversity and ecosystem stability. We have no option but to understand ecological complexity and act accordingly.

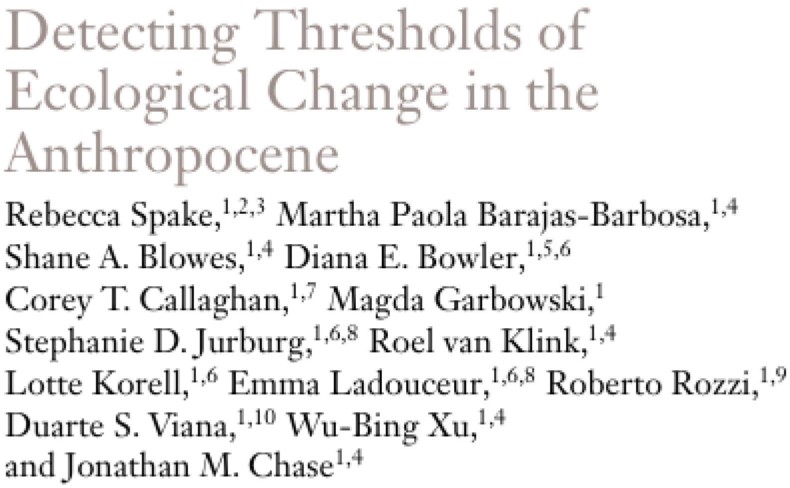


Novel Disturbance Regimes and Ecological Responses

Monica G. Turner[1] and Rupert Seidl[2,3]

2023

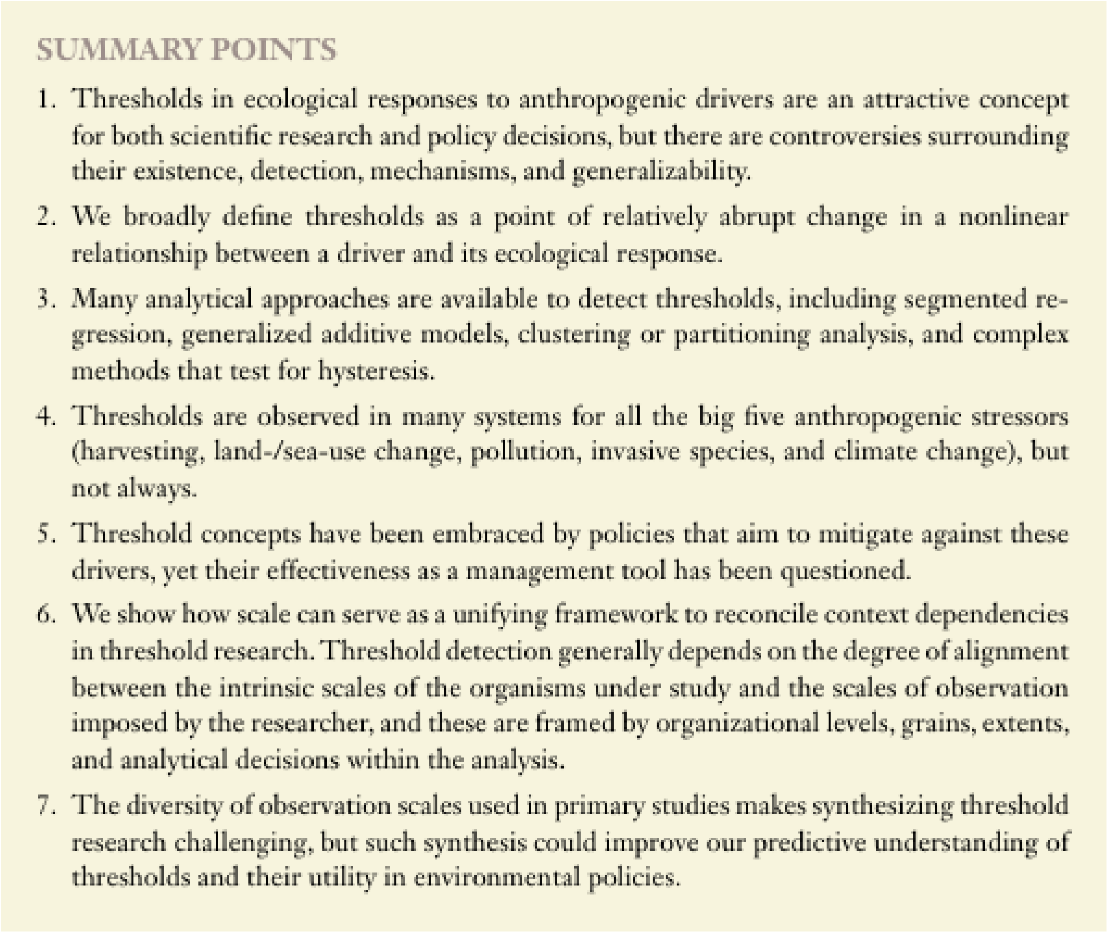
Many natural disturbances have a strong climate forcing, and concern is rising about how ecosystems will respond to disturbance regimes to which they are not adapted. Novelty can arise either as attributes of the disturbance regime (e.g., frequency, severity, duration) shift beyond their historical ranges of variation or as new disturbance agents not present historically emerge. How much novelty ecological systems can absorb and whether changing disturbance regimes will lead to novel outcomes is determined by the ecological responses of communities, which are also subject to change. Powerful conceptual frameworks exist for anticipating consequences of novel disturbance regimes, but these remain challenging to apply in real-world settings. Nonlinear relationships (e.g., tipping points, feedbacks) are of particular concern because of their disproportionate effects. Future research should quantify the rise of novelty in disturbance regimes and assess the capacity of ecosystems to respond to these changes. Novel disturbance regimes will be potent catalysts for ecological change.



Detecting Thresholds of Ecological Change in the Anthropocene

Rebecca Spake,[1,2,3] Martha Paola Barajas-Barbosa,[1,4]
Shane A. Blowes,[1,4] Diana E. Bowler,[1,5,6]
Corey T. Callaghan,[1,7] Magda Garbowski,[1]
Stephanie D. Jurburg,[1,6,8] Roel van Klink,[1,4]
Lotte Korell,[1,6] Emma Ladouceur,[1,6,8] Roberto Rozzi,[1,9]
Duarte S. Viana,[1,10] Wu-Bing Xu,[1,4]
and Jonathan M. Chase[1,4]

2022



SUMMARY POINTS

1. Thresholds in ecological responses to anthropogenic drivers are an attractive concept for both scientific research and policy decisions, but there are controversies surrounding their existence, detection, mechanisms, and generalizability.
2. We broadly define thresholds as a point of relatively abrupt change in a nonlinear relationship between a driver and its ecological response.
3. Many analytical approaches are available to detect thresholds, including segmented regression, generalized additive models, clustering or partitioning analysis, and complex methods that test for hysteresis.
4. Thresholds are observed in many systems for all the big five anthropogenic stressors (harvesting, land-/sea-use change, pollution, invasive species, and climate change), but not always.
5. Threshold concepts have been embraced by policies that aim to mitigate against these drivers, yet their effectiveness as a management tool has been questioned.
6. We show how scale can serve as a unifying framework to reconcile context dependencies in threshold research. Threshold detection generally depends on the degree of alignment between the intrinsic scales of the organisms under study and the scales of observation imposed by the researcher, and these are framed by organizational levels, grains, extents, and analytical decisions within the analysis.
7. The diversity of observation scales used in primary studies makes synthesizing threshold research challenging, but such synthesis could improve our predictive understanding of thresholds and their utility in environmental policies.

BUT!

I don’t see reviews that:

- dive into the theory’s basics or evidence for those basics
- evaluate theory’s parts across scales

Theory:

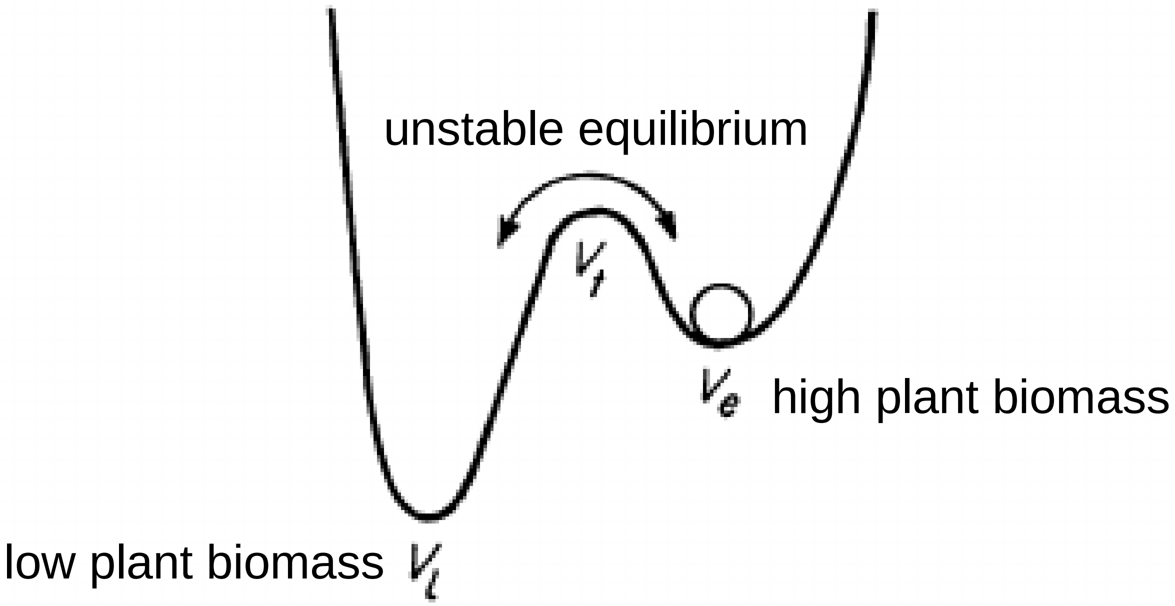
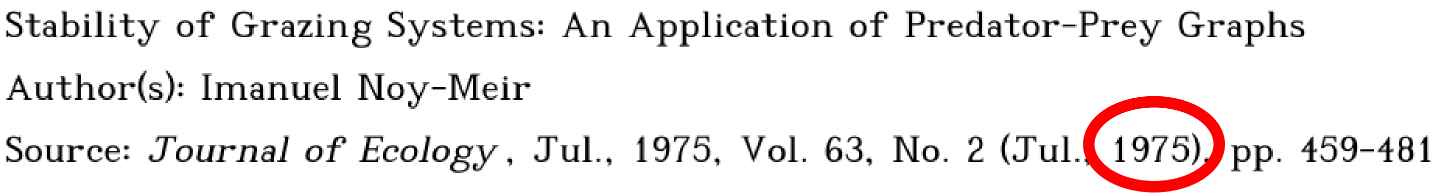


FIG. 6. A physical model of the two-steady-states situation.



Stability of Grazing Systems: An Application of Predator-Prey Graphs

Author(s): Imanuel Noy-Meir

Source: *Journal of Ecology*, Jul., 1975, Vol. 63, No. 2 (Jul., 1975), pp. 459-481

Theory:

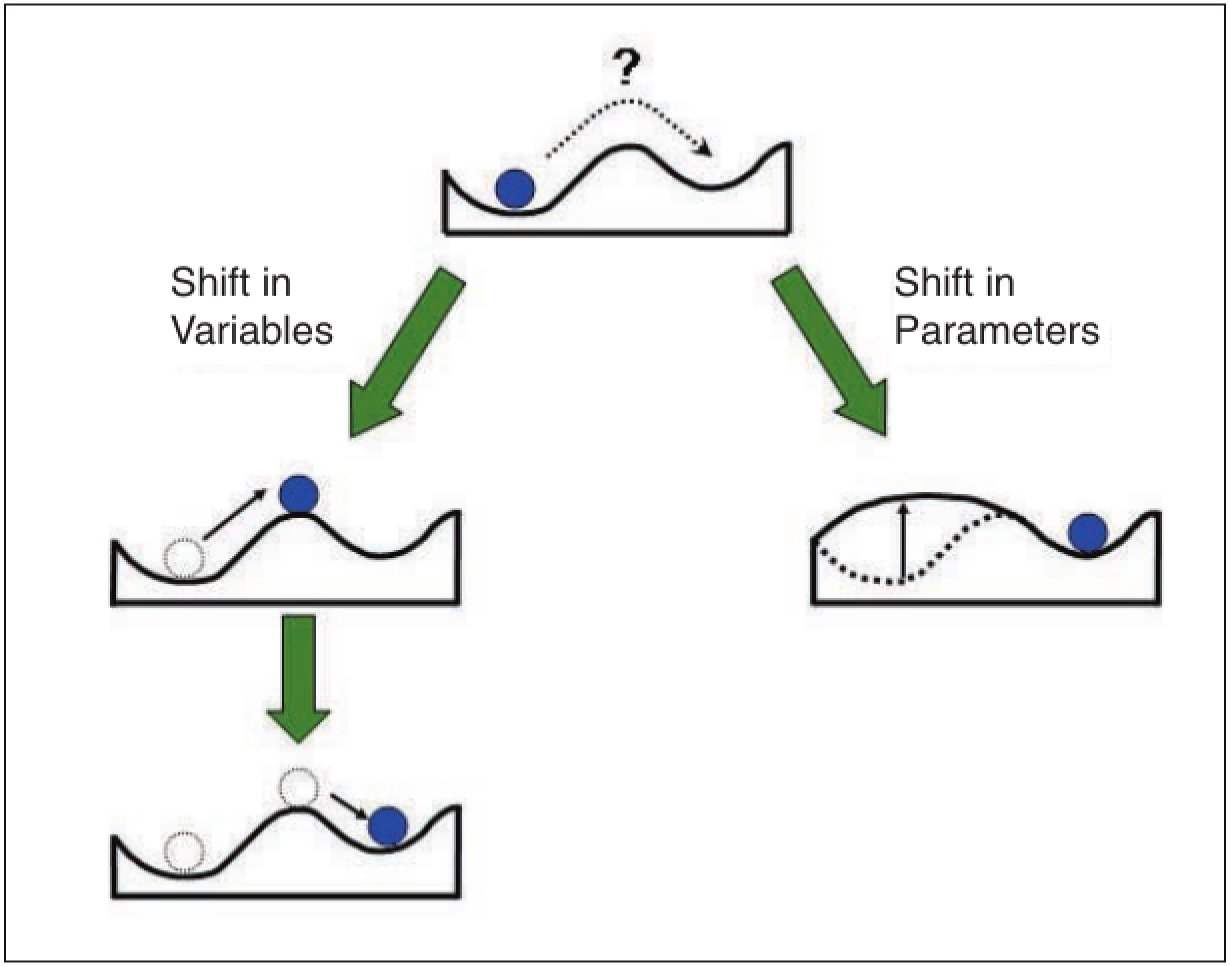


Figure 1. *Two-dimensional ball-in-cup diagrams showing (left) the way in which a shift in state variables causes the ball to move, and (right) the way a shift in parameters causes the landscape itself to change, resulting in movement of the ball.*

Alternative stable states in ecology

BE Beisner[1], DT Haydon[1], and K Cuddington[2]

Front Ecol Environ 2003; 1(7): 376–382

~ 1700 citations

Theory:

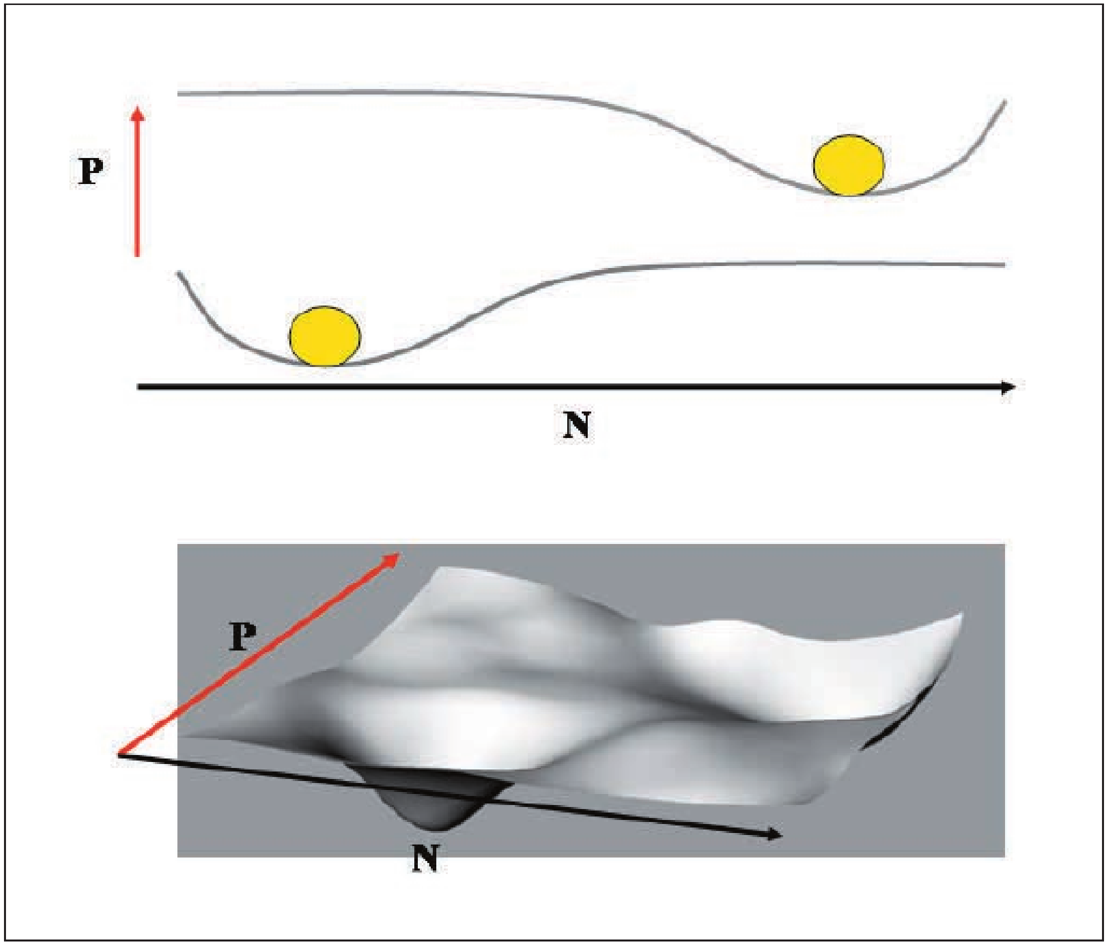


Figure 3. *The distinction between the community and ecosystem approaches lies mainly in what one considers a variable and a parameter. In the ecosystem perspective (top), a parameter P is changed according to the vertical red arrow in response to some external factor. The community equilibrium point moves along the horizontal axis (N) driven by the parameter change. There are no feedbacks between the state variable N and the parameter P. In the community perspective (bottom), the former parameter P is now a state variable included in the model, because P is subject to rapid feedback from the state variables modeled. Perturbations caused by forces external to the variables N and P can move the community ball around on the landscape. The landscape is now defined jointly by N and P and remains fixed.*

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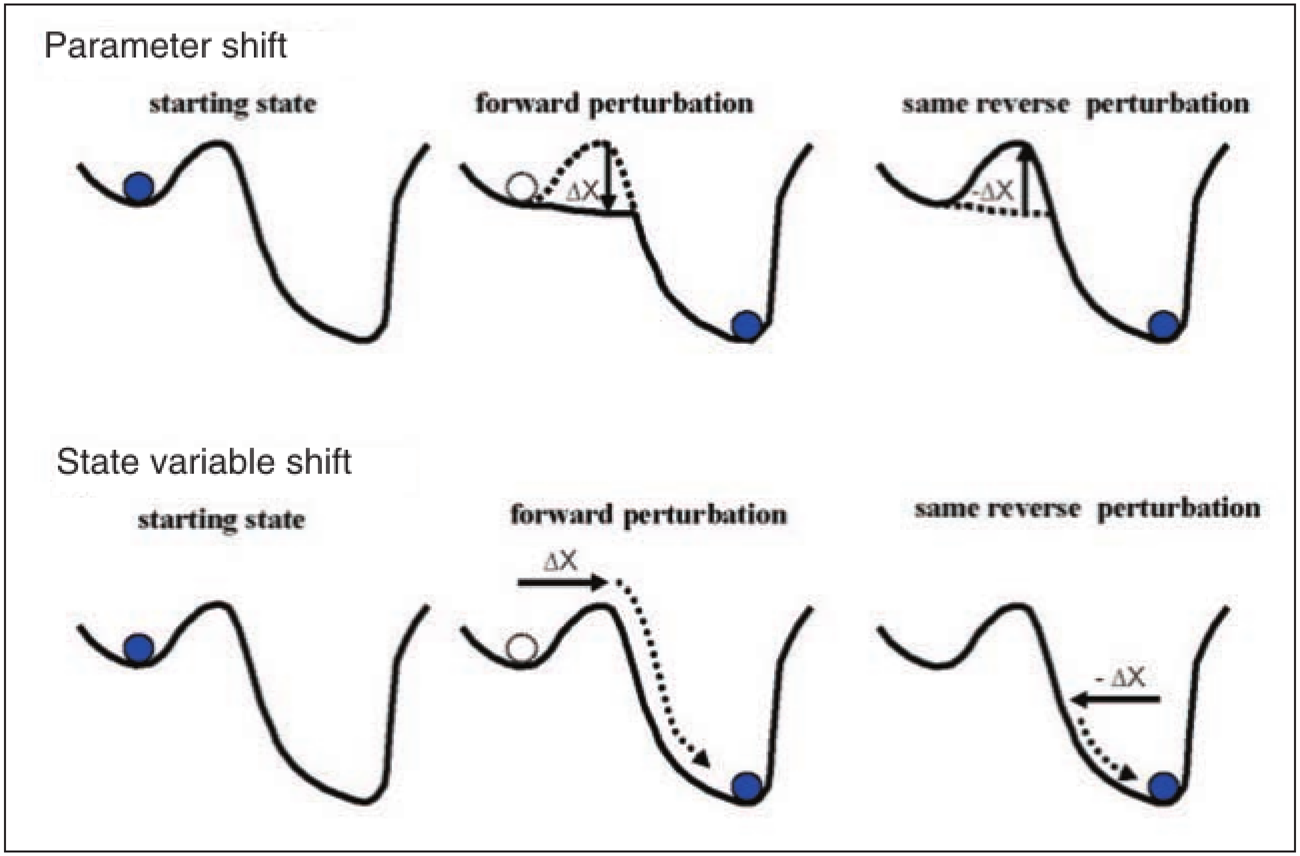


Figure 5. *(top) Hysteresis resulting from a parameter perturbation causing landscape changes that force the ball to move to another state, but application of an equal but opposite perturbation fails to return the community to its original state. (bottom) A possible analogous characteristic of state shifts arising from a state variable perturbation. The ball is pushed forward far enough to enter a new basin, but the same size perturbation in the other direction does not return it to its original position.*

Alternative stable states in ecology

BE Beisner[1], DT Haydon[1], and K Cuddington[2]

Front Ecol Environ 2003; 1(7): 376–382

Hysteresis defined

Theory:

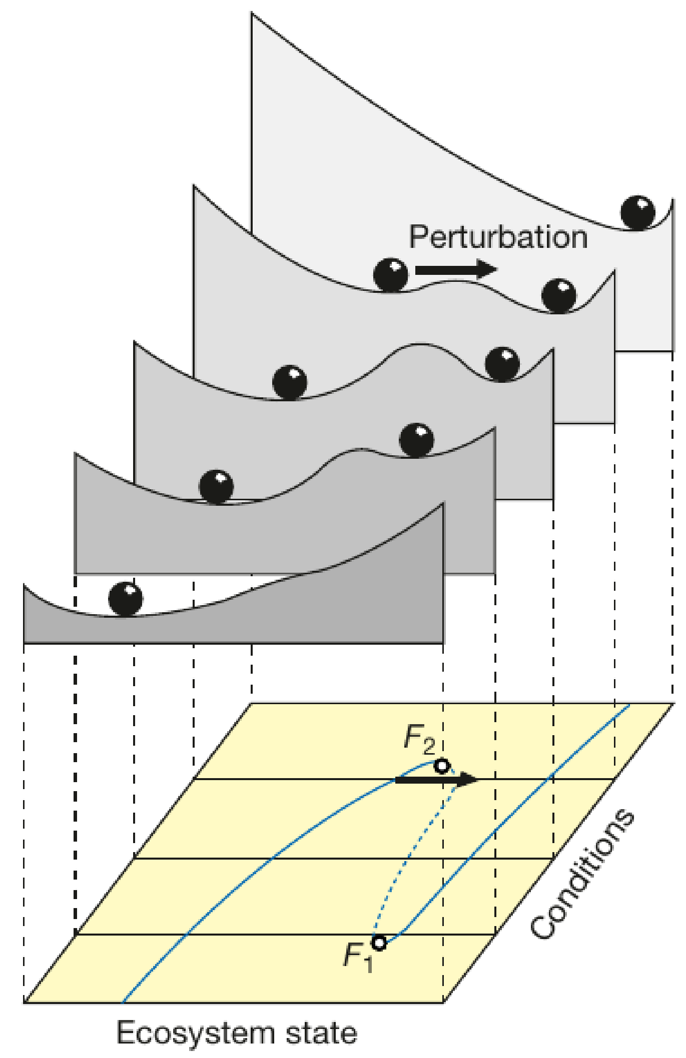


Figure 3 External conditions affect the resilience of multi-stable ecosystems to perturbation. The bottom plane shows the equilibrium curve as in Fig. 2. The stability landscapes depict the equilibria and their basins of attraction at five different conditions. Stable equilibria correspond to valleys; the unstable middle section of the folded equilibrium curve corresponds to a hill. If the size of the attraction basin is small, resilience is small and even a moderate perturbation may bring the system into the alternative basin of attraction.

Scheffer et al. 2011

Theory origins

Fig. 1

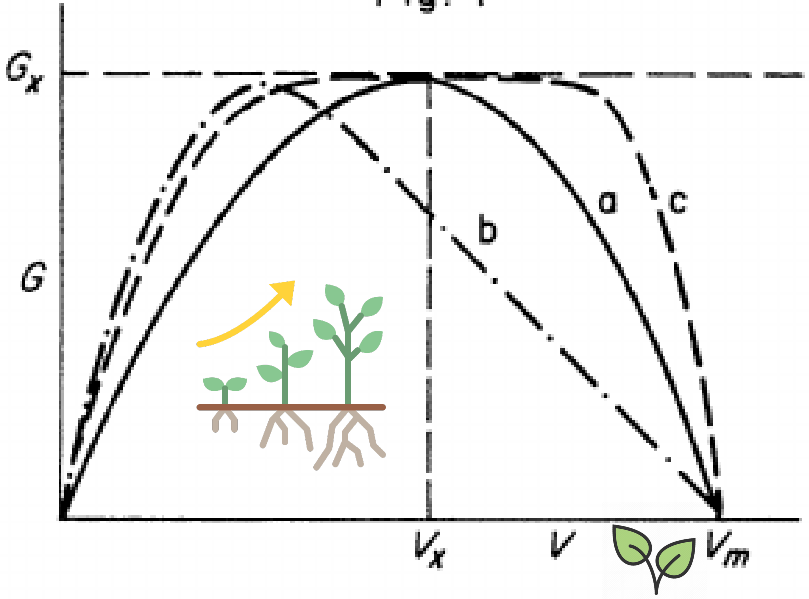


Fig. 2

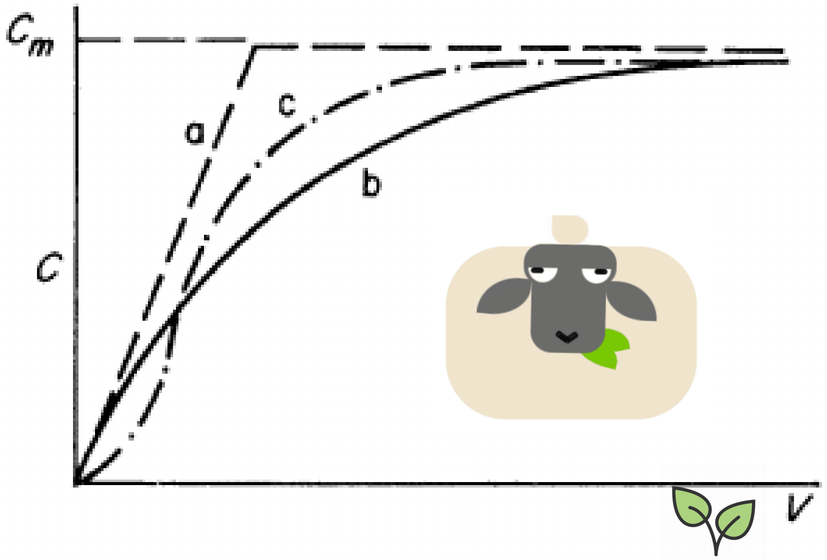


FIG. 1. Plant growth (*G*) as function of plant biomass (*V*). (a) Logistic growth; G_x—maximal growth, V_x—biomass at which growth is maximal. (b) and (c) Other possible curves.

FIG. 2. Consumption per animal (*c*) as function of plant biomass. c_m—Maximal consumption. (a) Linear to satiation. (b) Gradual satiation curve (e.g. Michaelis). (c) Sigmoid.

Noy-Meir 1975

Theory origins

Fig. 3

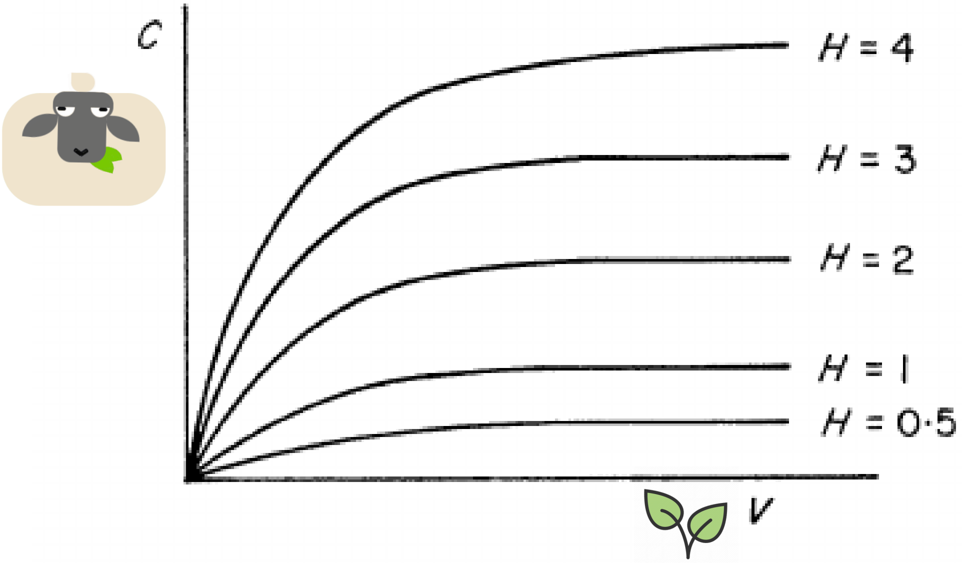
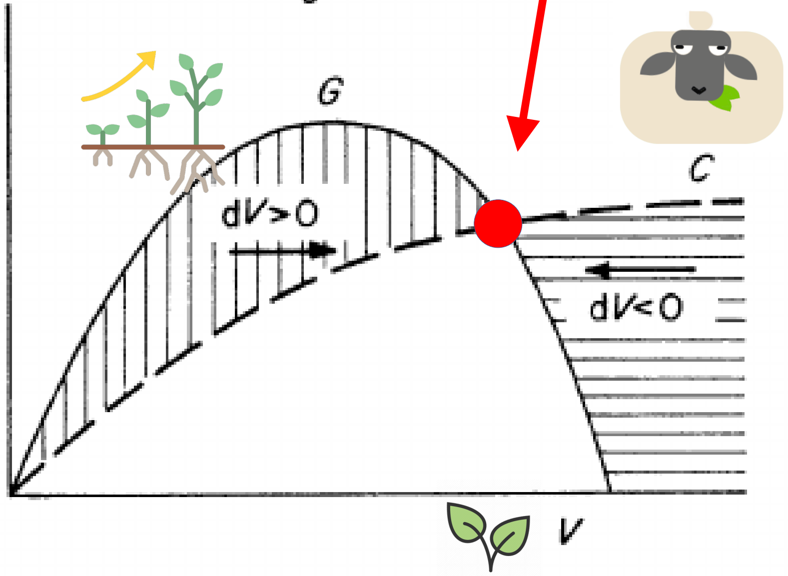


Fig. 4



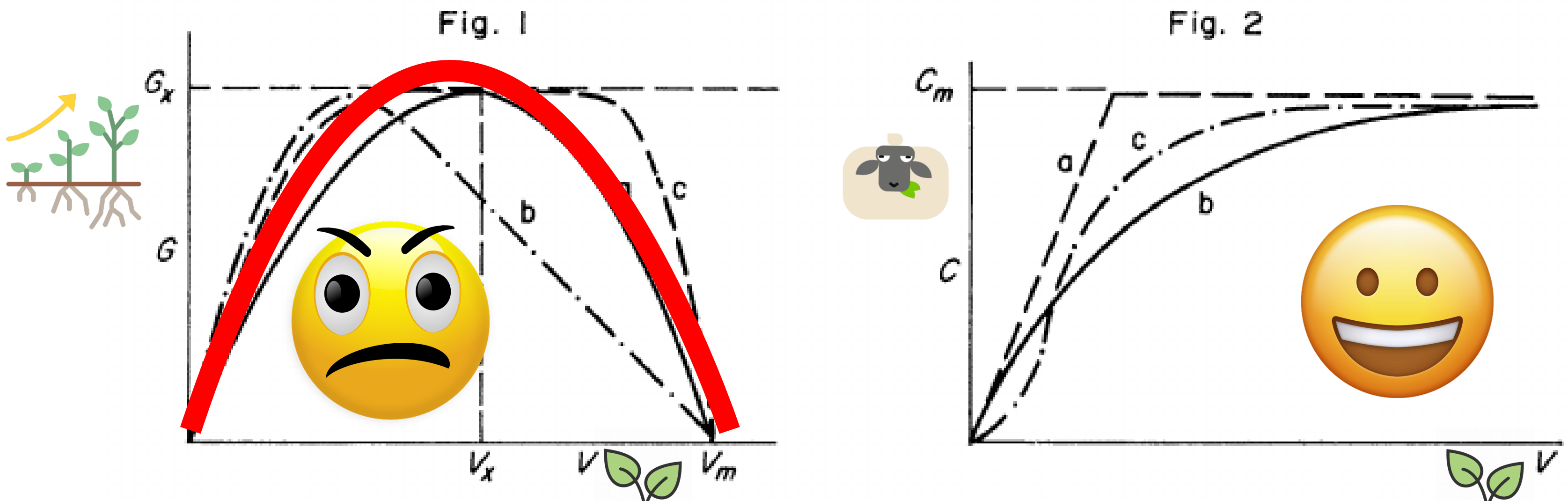
An equilibrium,
or stable state

FIG. 3. Consumption per unit area (C) as function of plant biomass (V) and herbivore density (H).

FIG. 4. Superimposition of growth $G(V)$ and consumption $C(V)$ functions of plant biomass.

Noy-Meir 1975

My problem with the theory:



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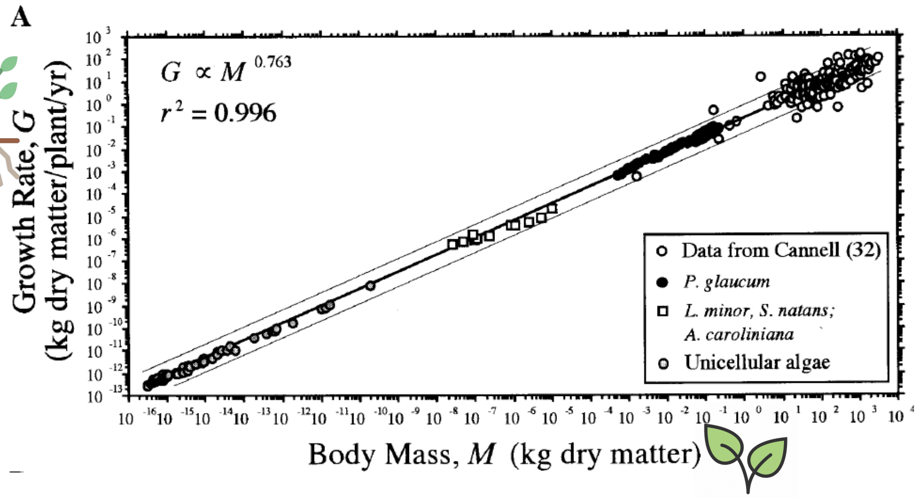
Noy-Meir 1975

because macroecology says:



Invariant scaling relationships for interspecific plant biomass production rates and body size

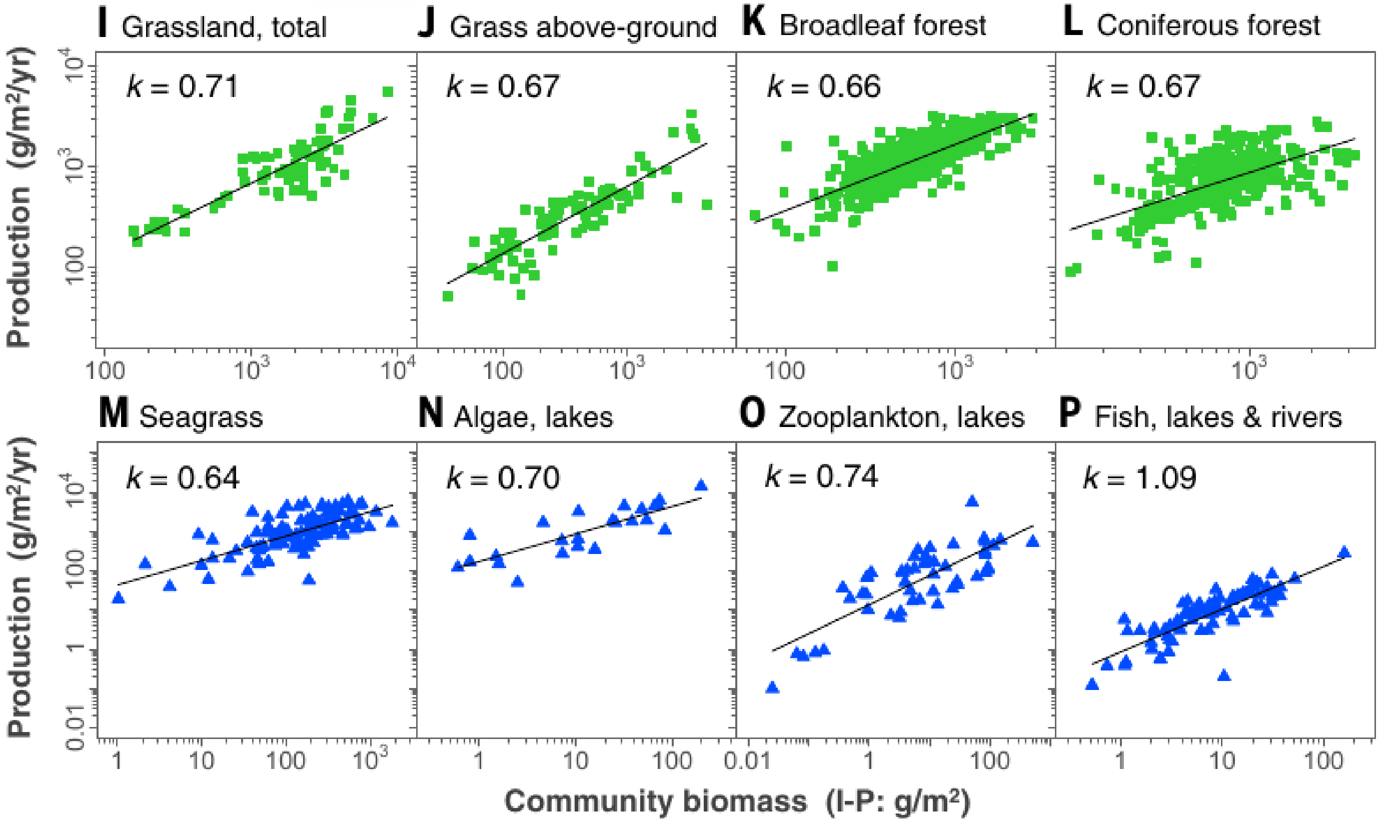
Karl J. Niklas*† and Brian J. Enquist‡§¶

2001

The predator-prey power law: Biomass scaling across terrestrial and aquatic biomes

Ian A. Hatton,* Kevin S. McCann, John M. Fryxell, T. Jonathan Davies, Matteo Smerlak, Anthony R. E. Sinclair, Michel Loreau

2015



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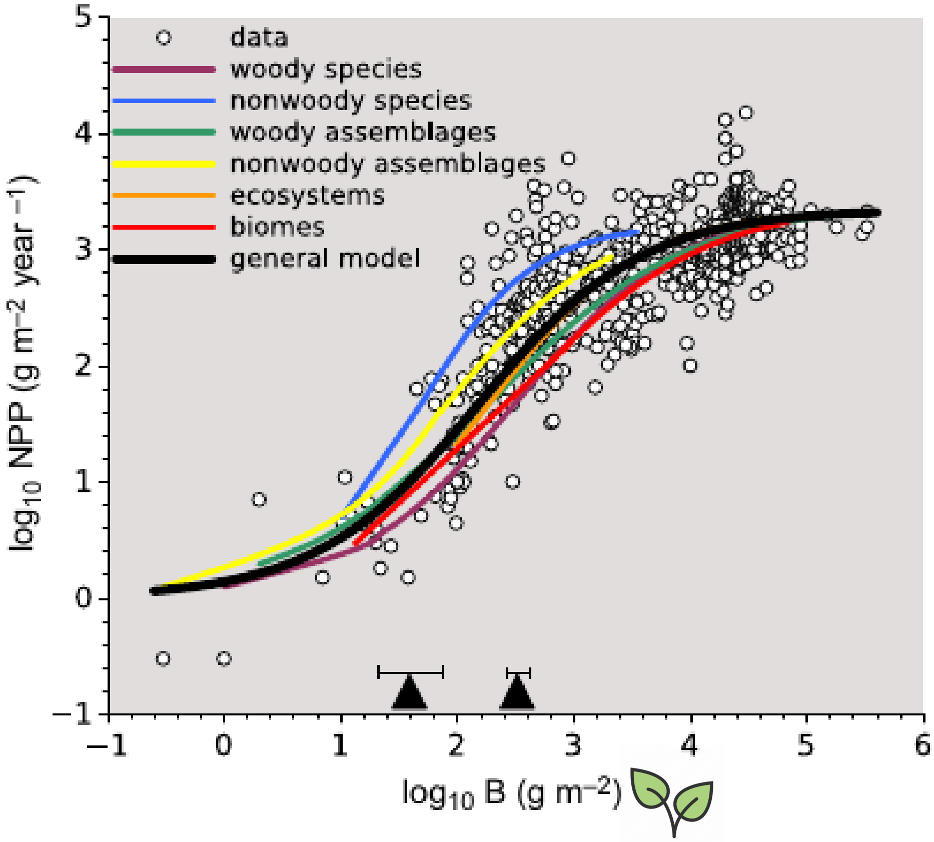


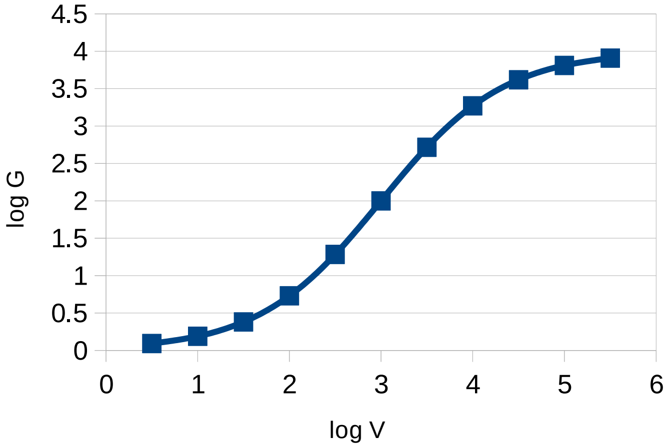
Fig. 3. General model for net primary production (NPP) scaling. The sigmoidal mixed-effect model included hierarchical levels as random effects. Triangles indicate tipping points (+95% confidence intervals) identified by segmented regression (Table 2).

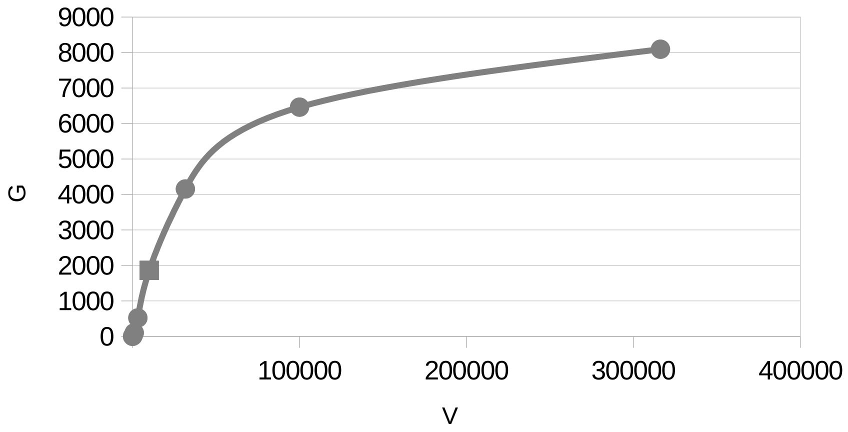
General allometric scaling of net primary production agrees with plant adaptive strategy theory and has tipping points

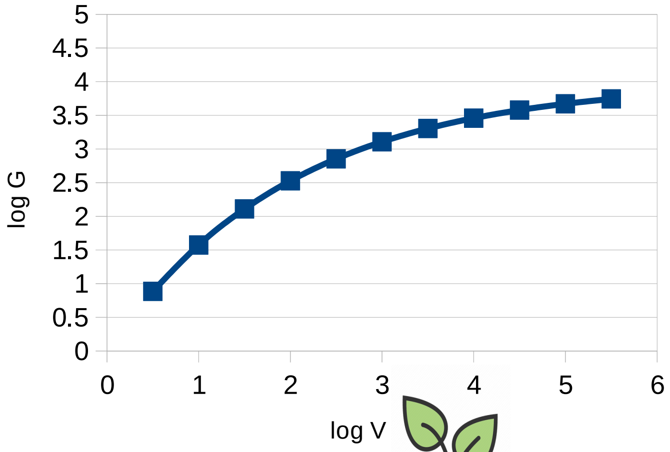
David G. Jenkins*[,1] **and Simon Pierce**[2]

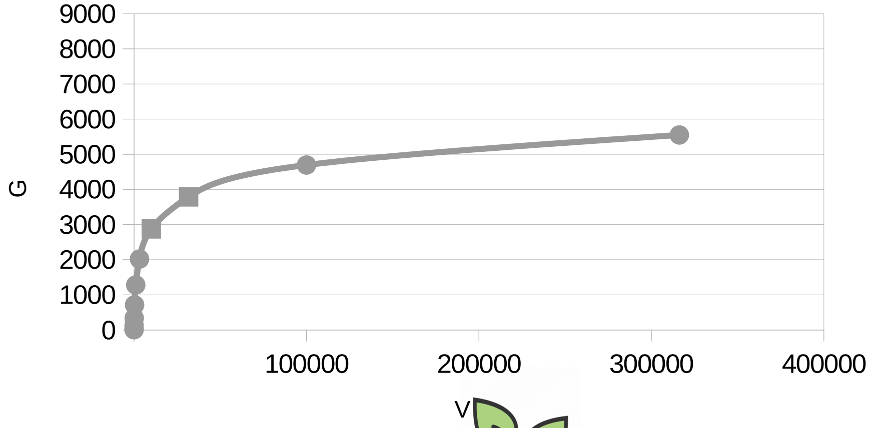
2017

What does an upward log-log line translate to?









So What? 1

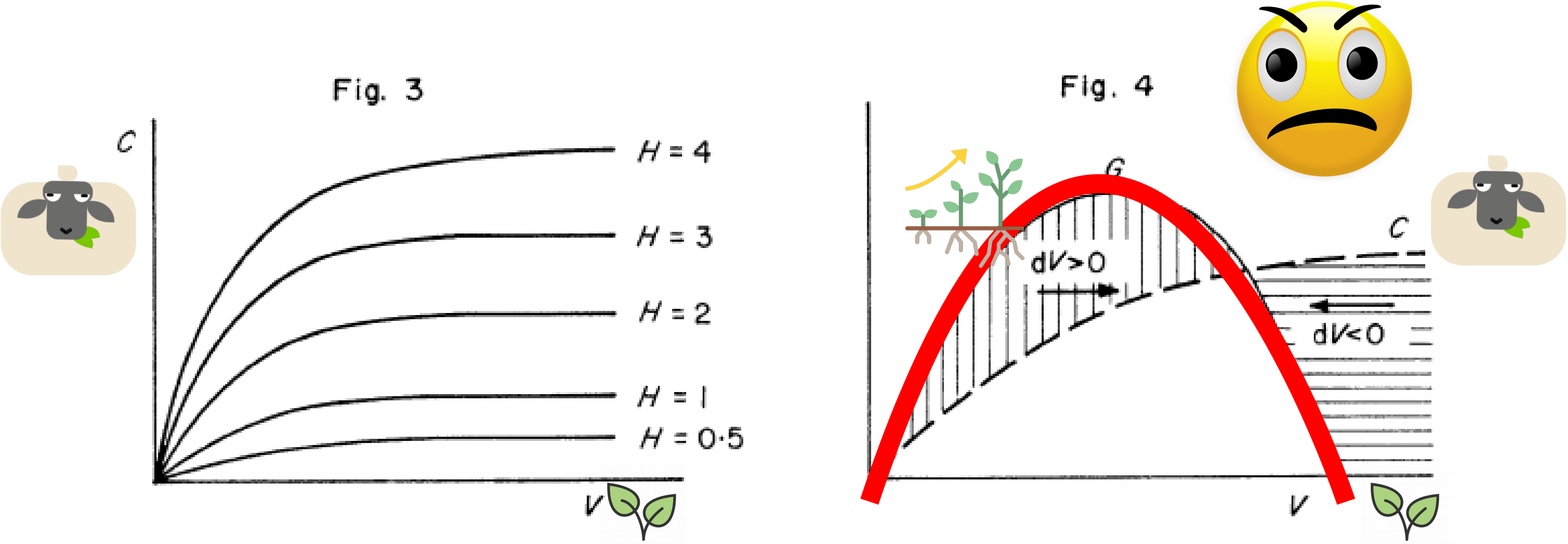


FIG. 3. Consumption per unit area (*C*) as function of plant biomass (*V*) and herbivore density (*H*).

FIG. 4. Superimposition of growth *G*(*V*) and consumption *C*(*V*) functions of plant biomass.

Noy-Meir
1975

So What? 1.5

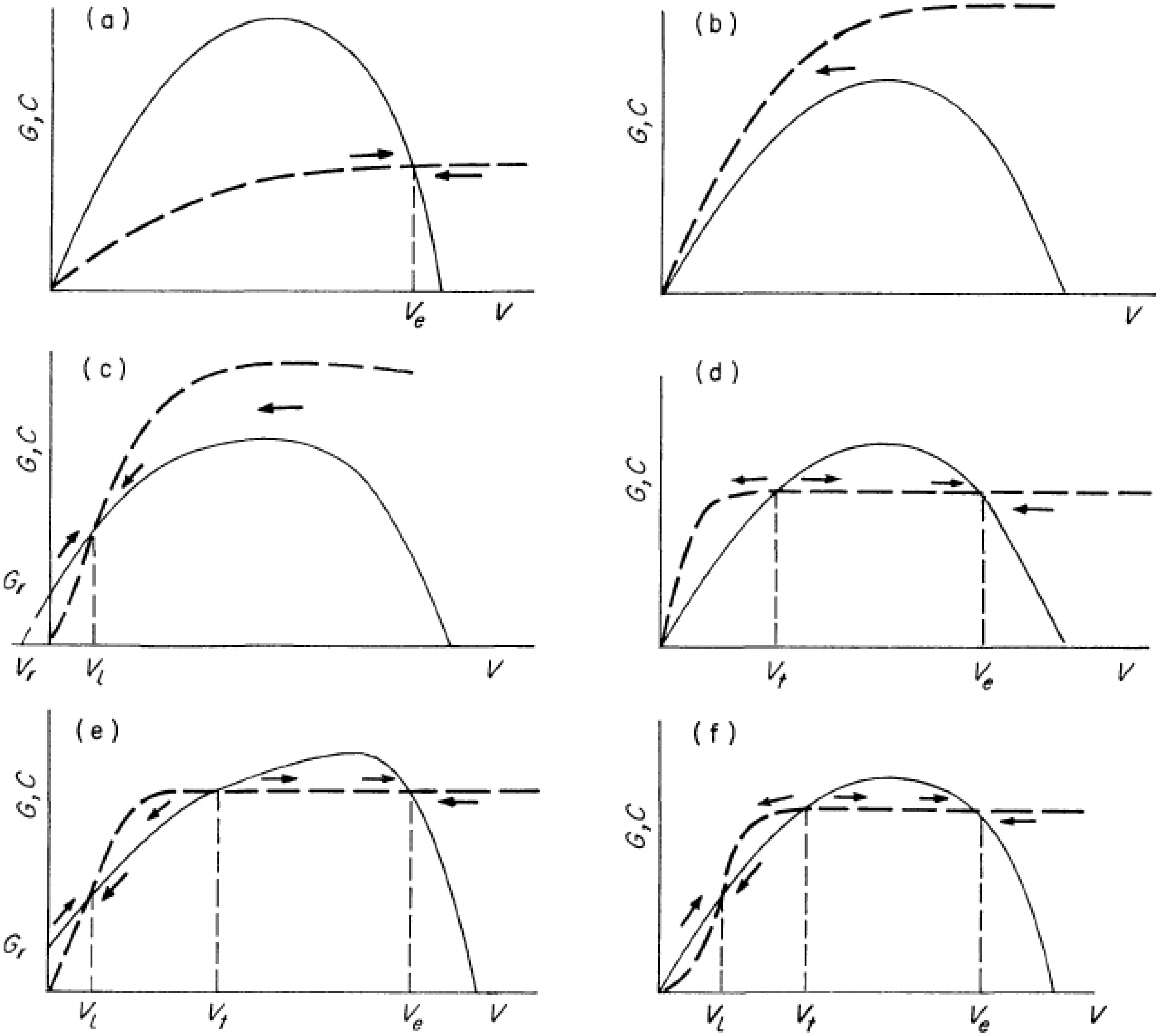


FIG. 5. Possible stability combinations of *G*- and *C*-curves at given *H*. (a) Undergrazed, stable steady-state (V_e). (b) Overgrazed to extinction. (c) Overgrazed to a low biomass steady-state (V_l); V_r—reserve (ungrazed) biomass, G_r—residual growth potential. (d) Steady-state and unstable turning point (V_t) to extinction. (e) Two steady-states (V_e, V_l) separated by turning point. (f) As (e), but caused by sigmoid *C*-curve, not by ungrazeable plant reserve.

Noy-Meir
1975

So What? 2

The entire premise of alternative stable states etc. etc. hinges on the **hump-shaped G curve**.

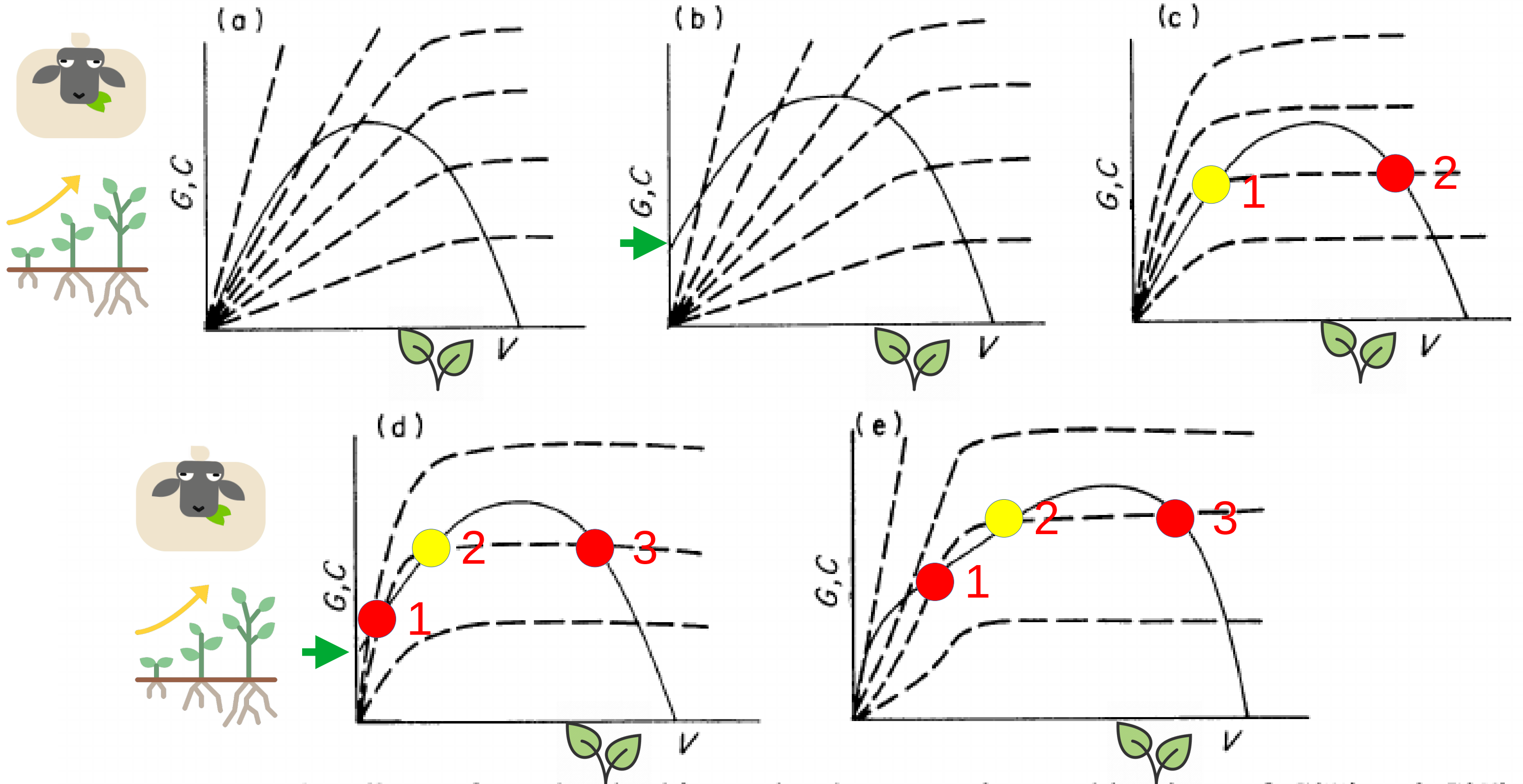
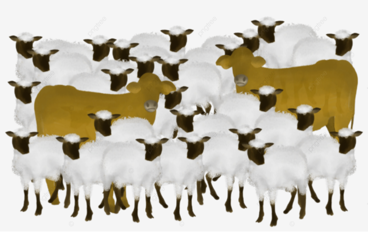


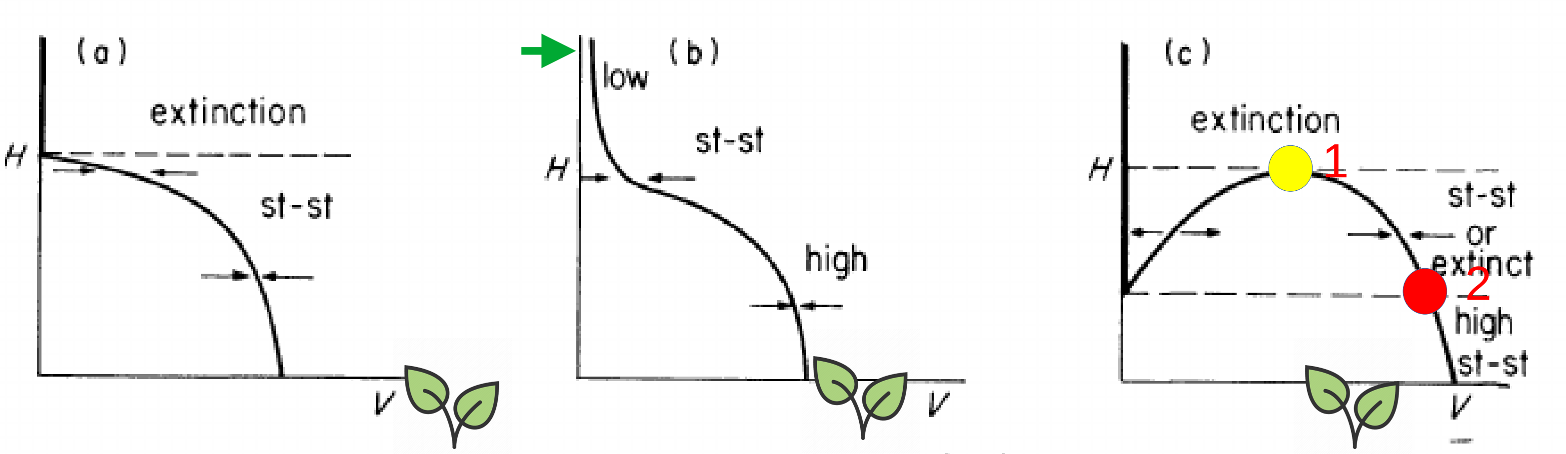
FIG. 8. The effects of varying herbivore density *H* on the combinations of $G(V)$ and $C(V)$. (a) *C* satiated at high *V*. (b) As (a), with plant reserve. (c) *C* satiated at low *V*. (d) As (c) with plant reserve. (e) *C* sigmoid.

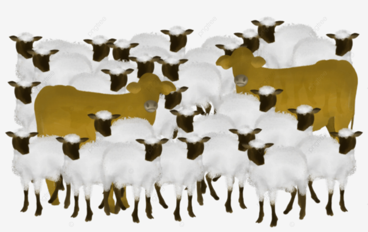
🔴 stable state
🟡 unstable pt.

Noy-Meir
1975

So What? 3







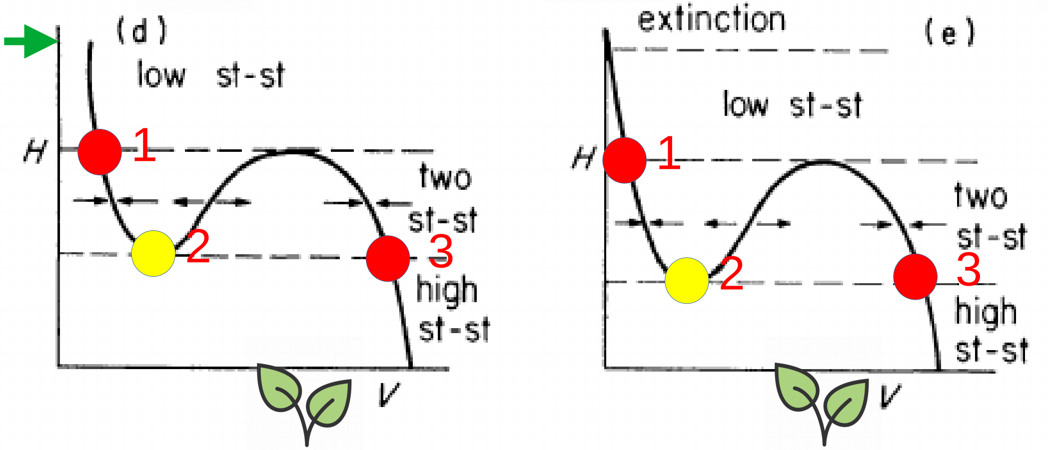


FIG. 9. Possible responses of plant–herbivore systems to increased herbivore density: the isocline of zero plant growth in the V–H plane; (a)–(e) correspond to (a)–(e) in Fig. 8. (a) Continuously stable to extinction. (b) Continuously stable, no extinction. (c) Discontinuously stable between high-V steady-state and extinction. (d) Discontinuously stable between high-V and low-V steady-states. (e) As (d), extinction also possible.

Noy-Meir
1975

H is assumed proportional to C; such as C = cH

So What? 4

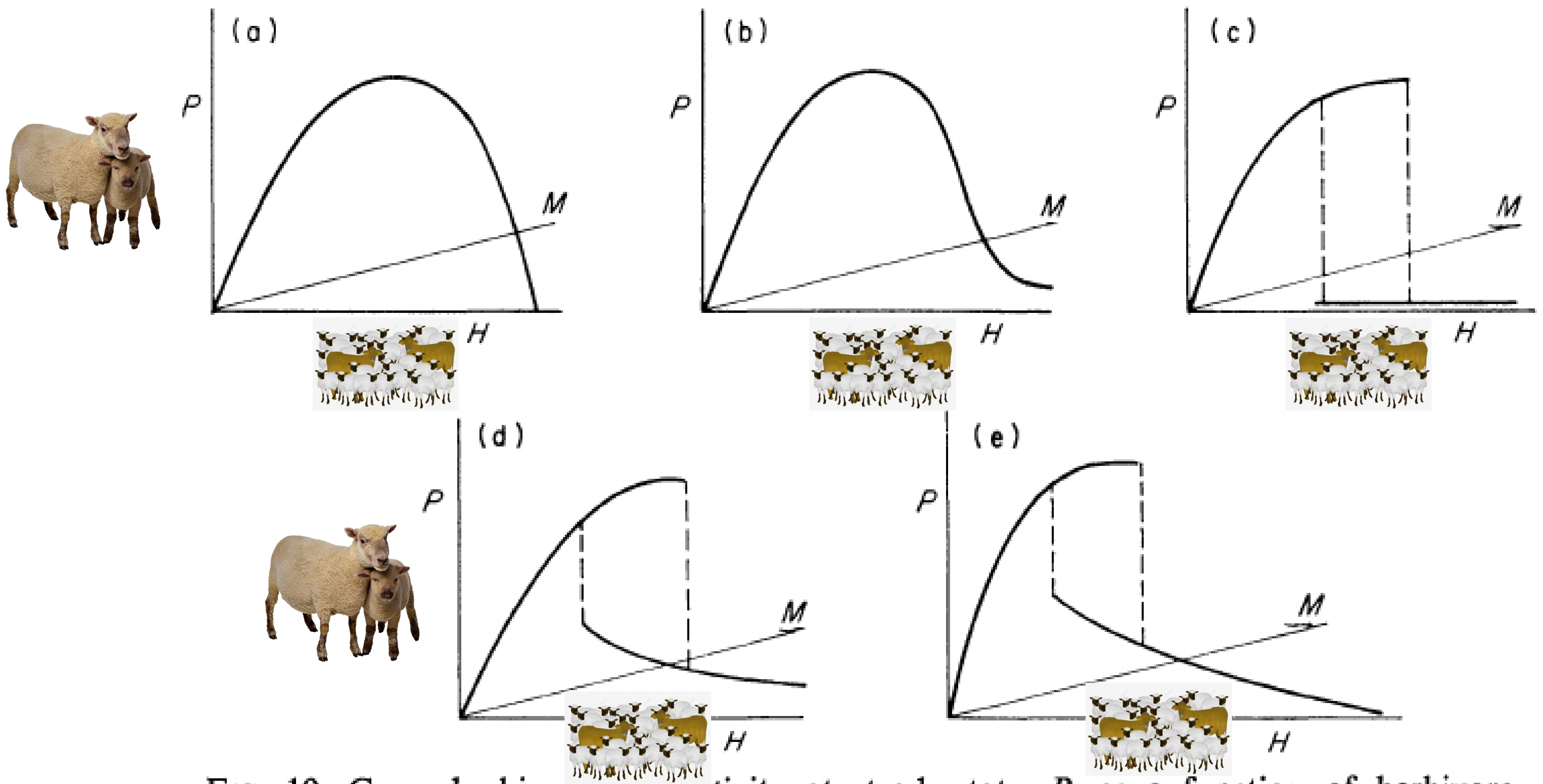
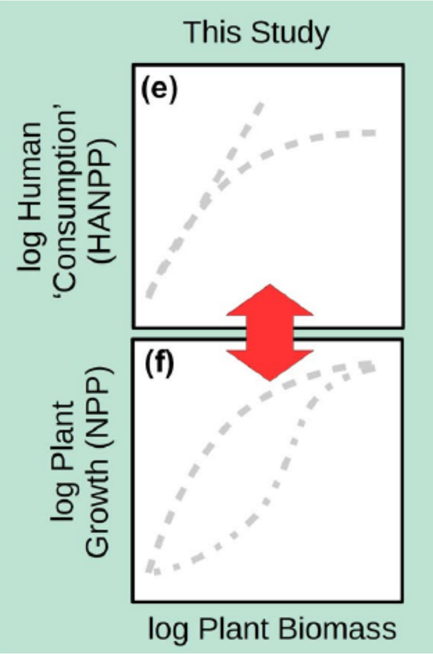


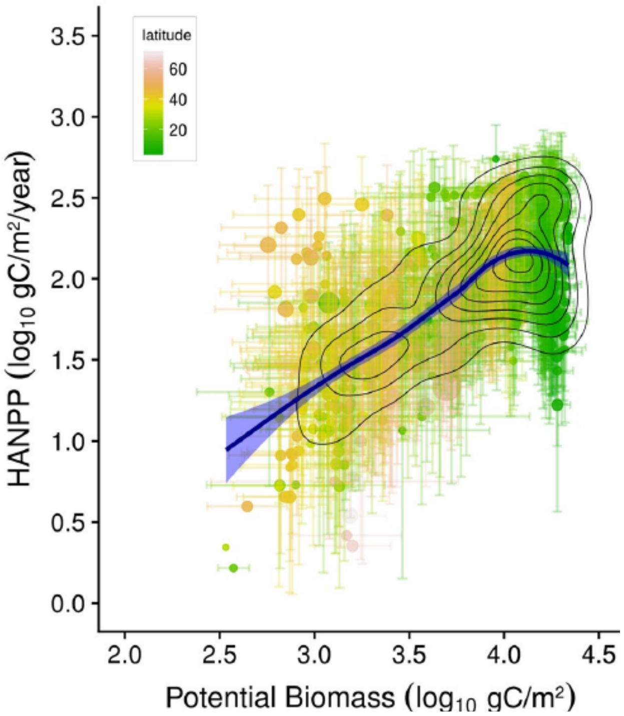
FIG. 10. Gross herbivore productivity at steady-state, *P*, as a function of herbivore density *H*. *M* is maintenance; net productivity is the difference between *P* and *M*. Cases (a)–(e) correspond to (a)–(e) in Figs 8 and 9. Broken vertical lines delimit the range of *H* in which two alternative steady-states, with different *P*, are possible.

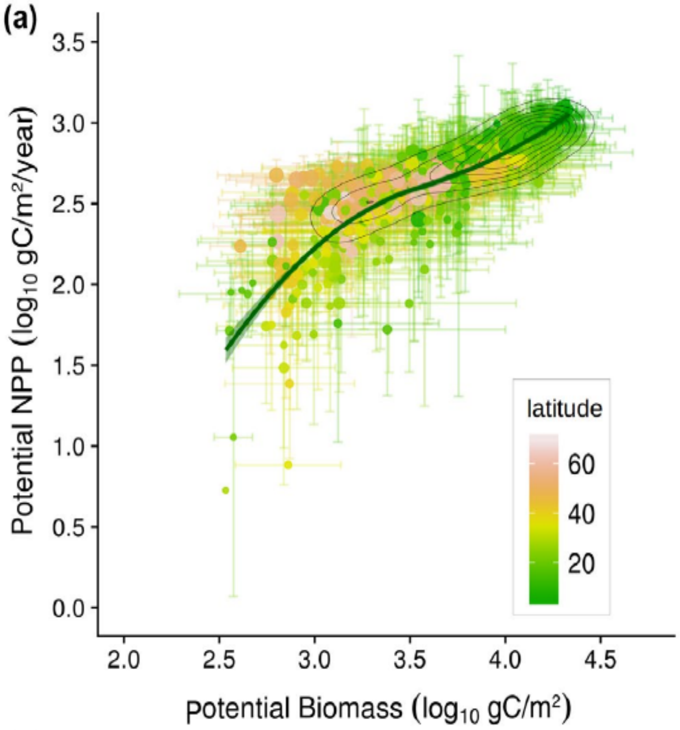
Noy-Meir
1975

P is assumed proportional to C; such as [net P = C – E - R]

What if the G curve is not hump-shaped?







Global human "predation" on plant growth and biomass

David G. Jenkins[1] | Helmut Haberl[2] | Karl-Heinz Erb[2] | Andrew L. Nevai[3]

2020

Given no hump-shaped G curve, then:

- no alternative stable states
- no catastrophic regime shifts.

Just smooth, reversible transitions / Thresholds / tipping points

IF G (NPP) and C (HANPP) lines even cross!

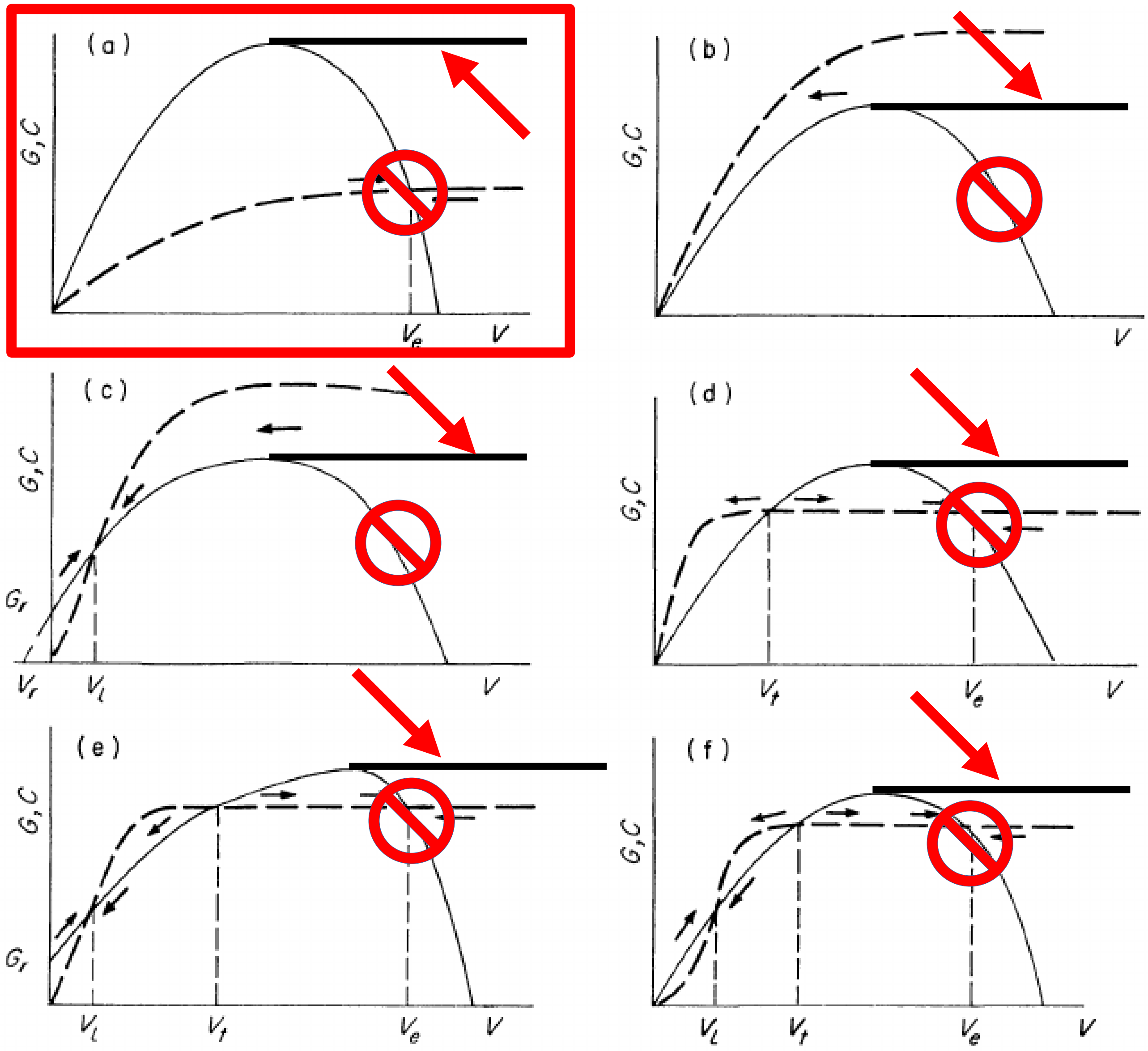


FIG. 5. Possible stability combinations of G- and C-curves at given H. (a) Undergrazed, stable steady-state (V_e). (b) Overgrazed to extinction. (c) Overgrazed to a low biomass steady-state (V_l); V_r—reserve (ungrazed) biomass, G_r—residual growth potential. (d) Steady-state and unstable turning point (V_t) to extinction. (e) Two steady-states (V_e, V_l) separated by turning point. (f) As (e), but caused by sigmoid C-curve, not by ungrazeable plant reserve.

Noy-Meir
1975

Consider an asymptotic G curve instead:

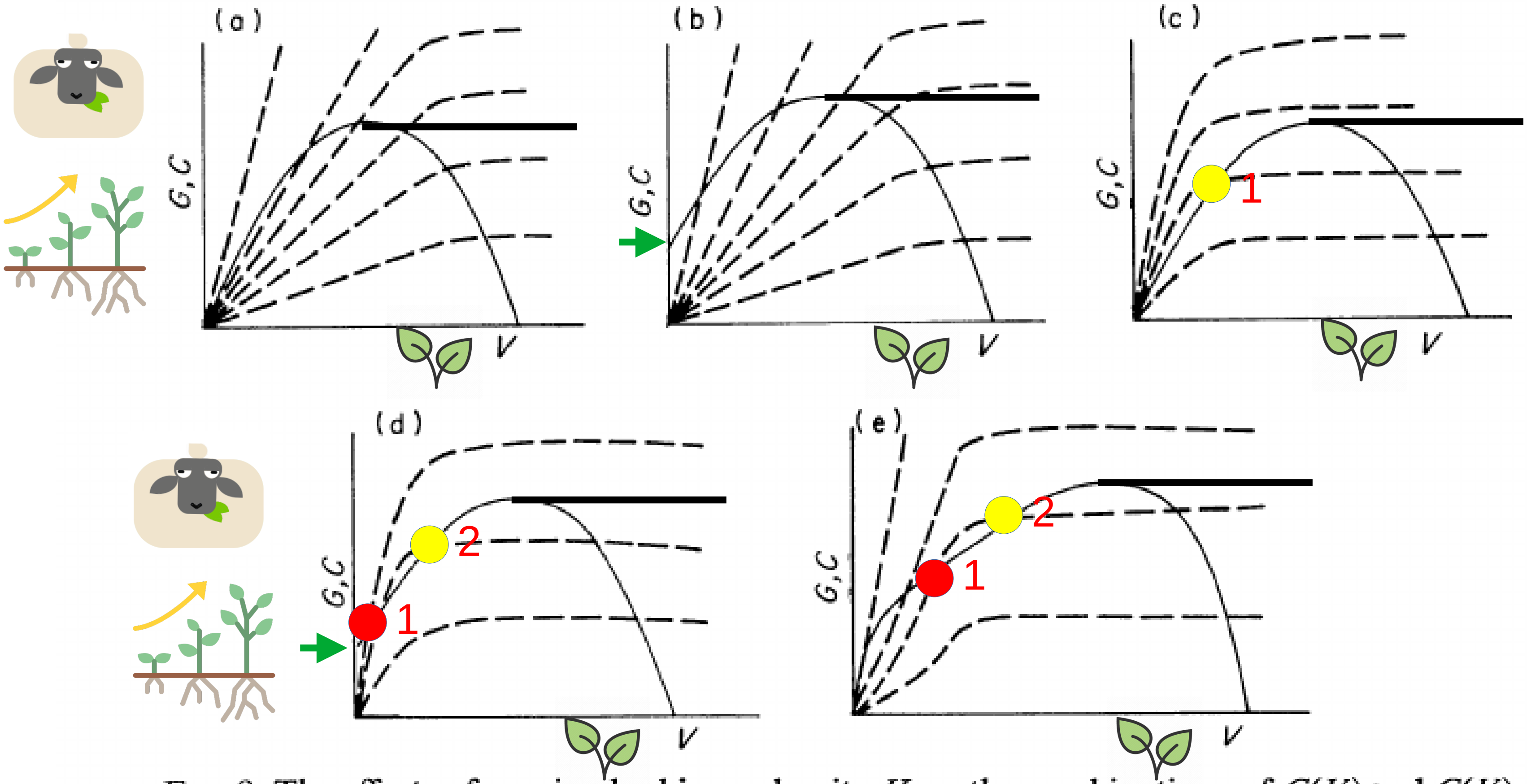


FIG. 8. The effects of varying herbivore density H on the combinations of $G(V)$ and $C(V)$. (a) C satiated at high V. (b) As (a), with plant reserve. (c) C satiated at low V. (d) As (c) with plant reserve. (e) C sigmoid.

Noy-Meir
1975

🔴 stable state
🟡 unstable pt.

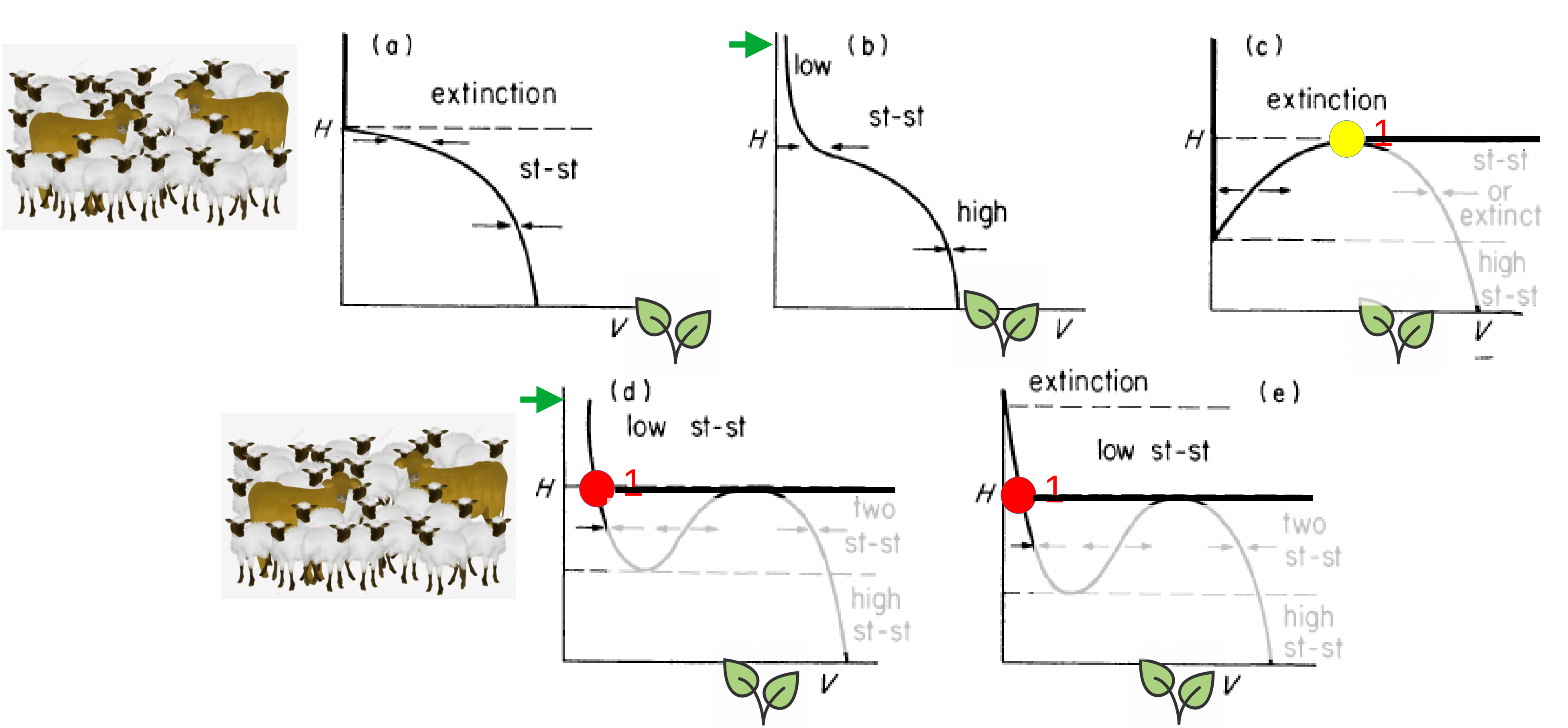
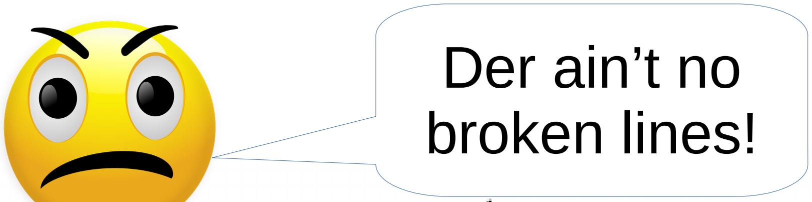
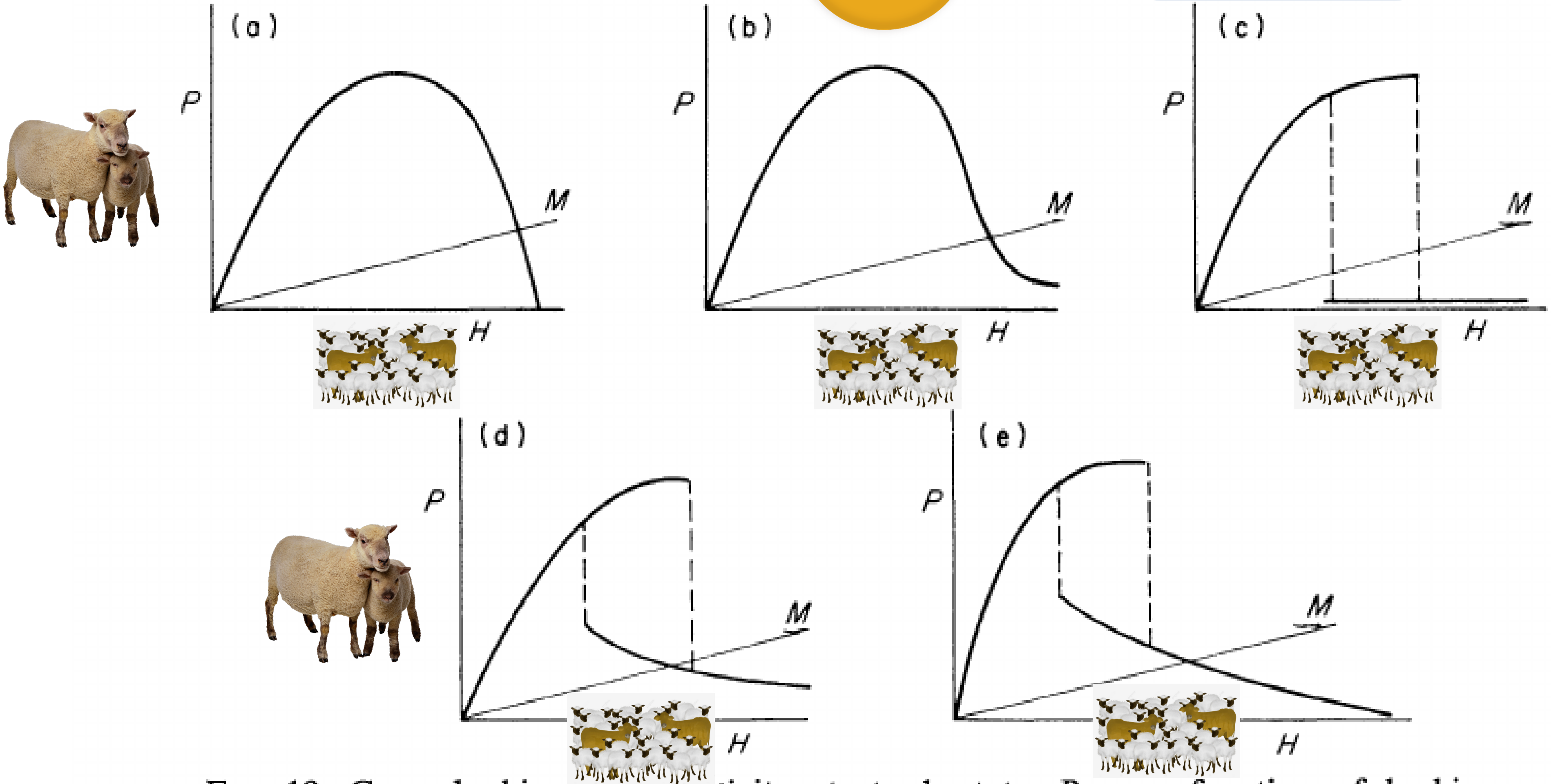


FIG. 9. Possible responses of plant–herbivore systems to increased herbivore density: the isocline of zero plant growth in the V–H plane; (a)–(e) correspond to (a)–(e) in Fig. 8. (a) Continuously stable to extinction. (b) Continuously stable, no extinction. (c) Discontinuously stable between high-V steady-state and extinction. (d) Discontinuously stable between high-V and low-V steady-states. (e) As (d), extinction also possible.

Noy-Meir
1975

H is assumed proportional to C; such as C = cH





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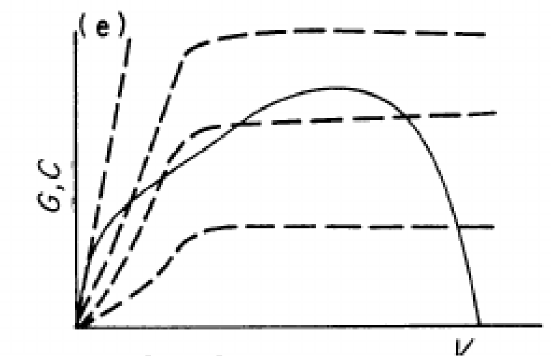
Noy-Meir
1975

P is assumed proportional to C; such as [net P = C – E - R]

Bottom Lines

The entire premise of alternative stable states etc. etc. hinges on the hump-shaped G curve.

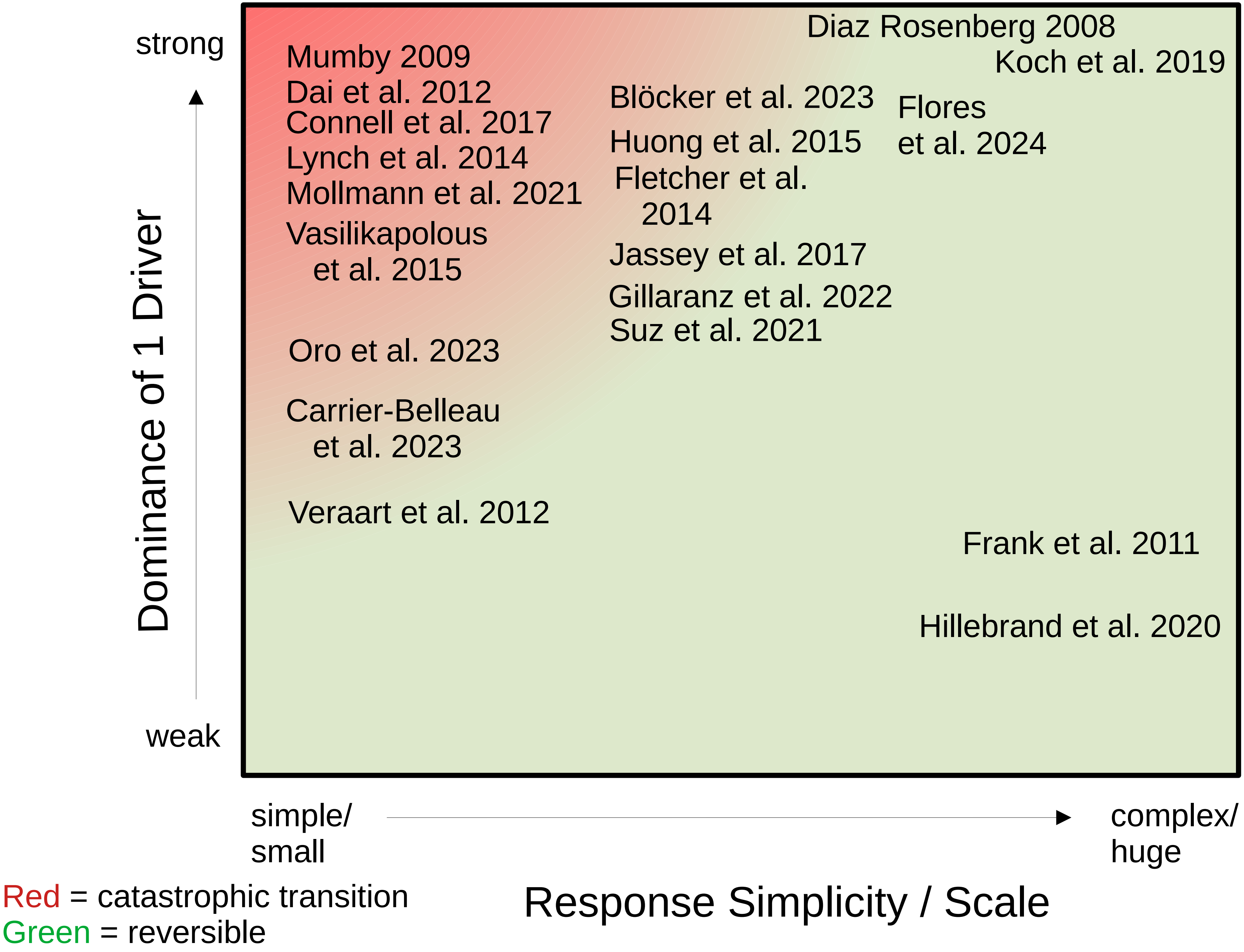


To recap:

- Two [allometric, macroecological] curves are needed, showing functional rate ~ structural quantity, which are assumed to relate to population size
- Shapes of curves determine potential equilibria

Questions:

- What % of studied systems have a legit basis to use these ideas?
- What % papers actually evaluate this before using it?
- Do answers depend on Marine / Freshwater / Terrestrial?
- Do answers depend on system simplicity / scale?


strong
weak
Dominance of 1 Driver
simple/
small
complex/
huge
Response Simplicity / Scale
Red = catastrophic transition
Green = reversible
Mumby 2009
Dai et al. 2012
Connell et al. 2017
Lynch et al. 2014
Mollmann et al. 2021
Vasilikapolous
et al. 2015
Oro et al. 2023
Carrier-Belleau
et al. 2023
Veraart et al. 2012
Diaz Rosenberg 2008
Koch et al. 2019
Blöcker et al. 2023
Huong et al. 2015
Fletcher et al.
2014
Jassey et al. 2017
Gillaranz et al. 2022
Suz et al. 2021
Flores
et al. 2024
Frank et al. 2011
Hillebrand et al. 2020