



The concept of resilience in ecology

Chosen examples from marine ecology

Sakina-Dorothee Ayata

Maitresse de conférences HDR à Sorbonne Université

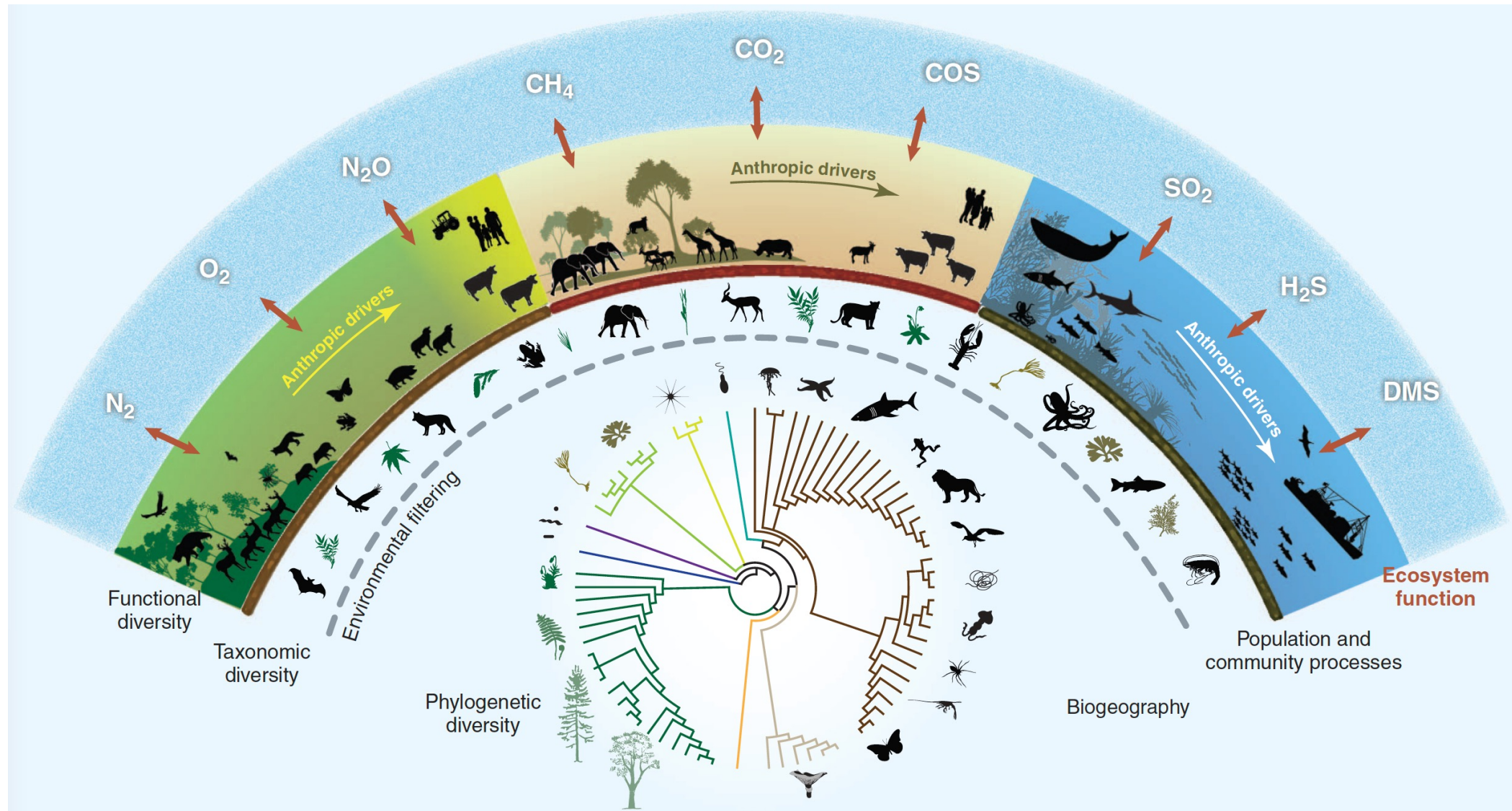
Laboratoire d'Océanographie et du Climat : Expérimentation et Approches Numériques (LOCEAN)

Sakina-dorothee.ayata@locean.ipsl.fr

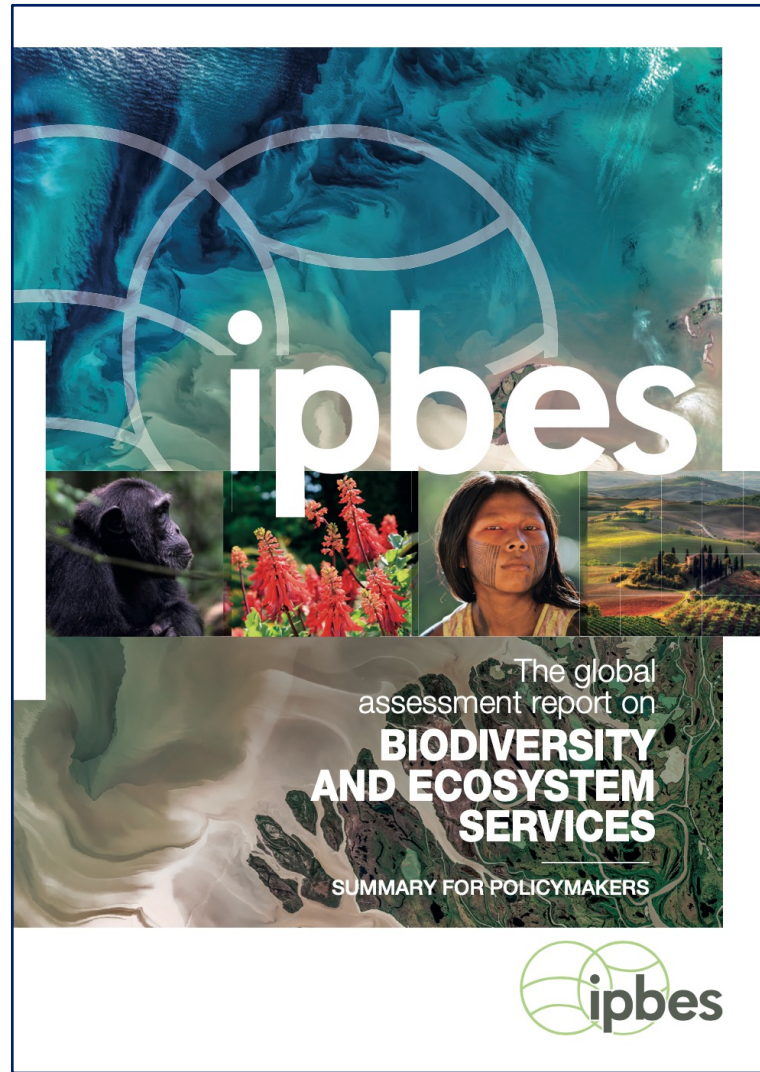


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Biodiversity and ecosystems



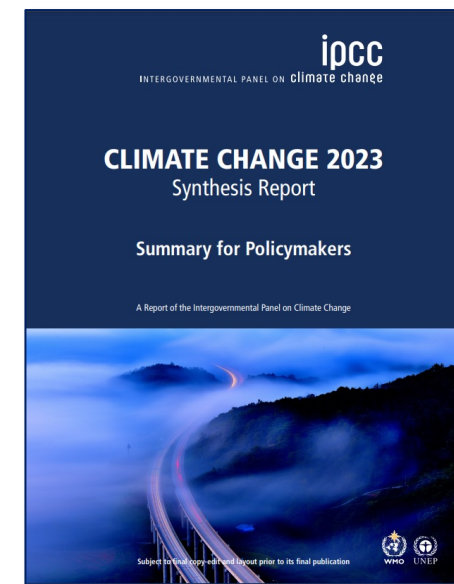
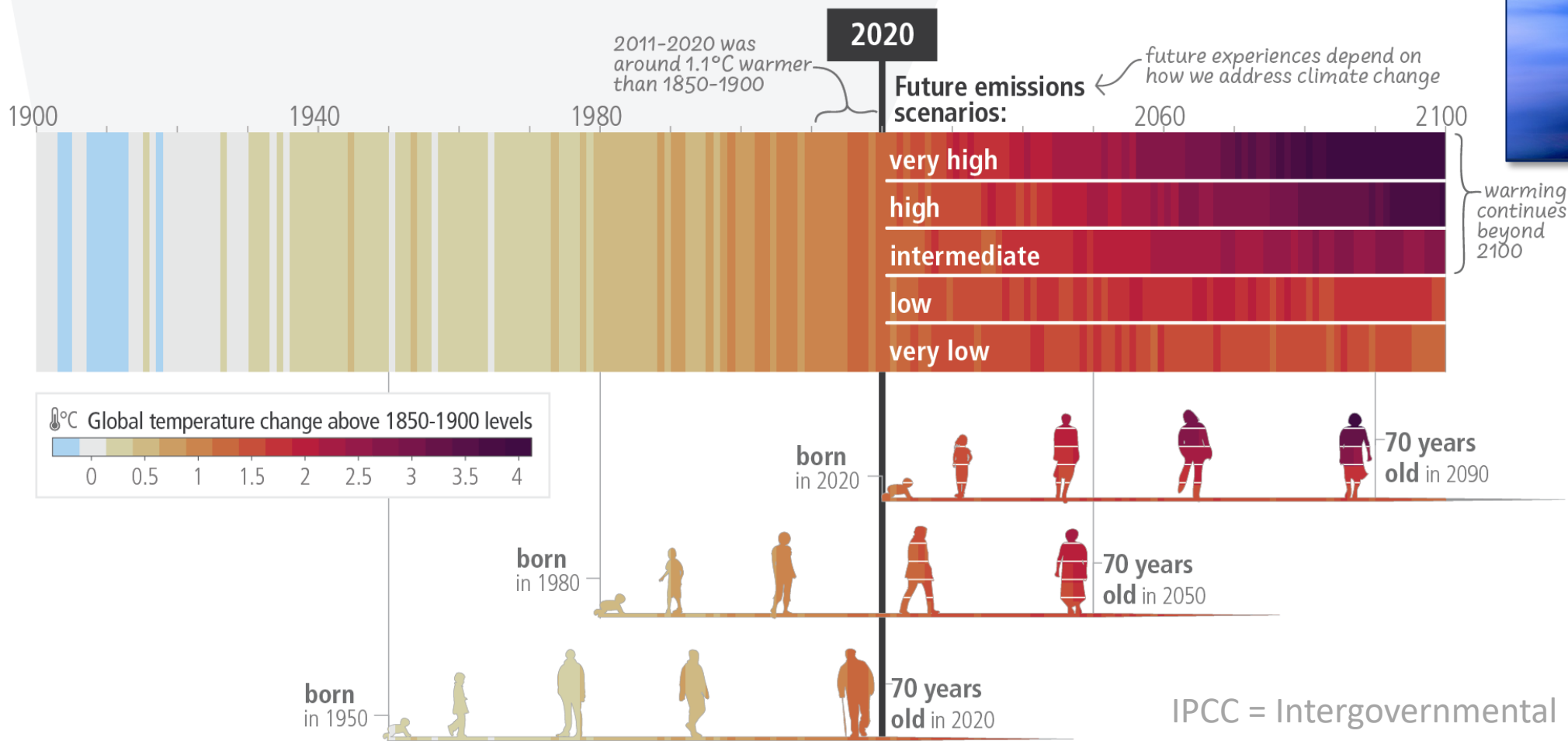
Biodiversity and ecosystems



How to increase the resilience of ecosystems to perturbations?

Biodiversity and ecosystems

The extent to which current and future generations will experience a hotter and different world depends on choices now and in the near-term



Defining the resilience in ecology

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RESILIENCE AND STABILITY OF ECOLOGICAL SYSTEMS

C. S. Holling

Institute of Resource Ecology, University of British Columbia, Vancouver, Canada

Holling (1973)

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Volker Grimm · Christian Wissel

Babel, or the ecological stability discussions: an inventory and analysis of terminology and a guide for avoiding confusion

Grimm & Wissel (1997)

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Stability term and definition	Authors who use the term in the first column in more or less the same way	Terms with definitions mainly the same as in the first column
<p>Table 2 The basic vocabulary of the ecological stability discussion and classification of the definitions from the literature. <i>First column:</i> the six stability concepts in ecology which remain after "distillation" of the definitions from Table 1. <i>Second column:</i> literature references for the definitions which agree in the main with the definitions from the first column. "Connell and Sousa 83:97", for example, means that the corresponding definition is to be found in Connell and Sousa (1983) on page 97. <i>Third column:</i> lists of the definitions (together with references) with essentially the same properties as those in the first column, but which use a different term for the property</p>		
(1) Constancy: Staying essentially unchanged	Connell and Sousa 83:97 Gigon 83:97 Harrison 79:661 Lewontin 69:21 Orians 75:141 Remmert 89:286	Biomass stability – King and Pimm 1983:329 Ecological stability* – Zwißler 78:15 Functional stability – Rejmánek 92:455 Perceived stability – Begon et al. 90:802 Persistence – Rabel 90:328 Stability* – Haber 79:24 Stability – Murdoch 70:497 Stability – Putman and Wratten 85:338 Temporal stability – Preston 69:9
(2) Resilience: Returning to the reference state (or dynamic) after a temporary disturbance	Harrison 79:660 Leps et al. 82:54 Putman and Wratten 85:339 Ulrich 92:181 Westman 78:705	Stability – Hallet 91:383 Stability – Holling 73:17 Stability – Pimm 84:322 Stability – Steele 74:180 Adjustment – Connell and Sousa 83:790 Connective stability – Sijak 74:280 Elasticity – Gigon 83:98 Elasticity* – Remmert 84:286 [Global, local] stability – Begon et al. 90:792 Mathematical stability – Danielson and Stenseth 92:83 Regulation – Murdoch 70:497 Resiliency – Kuss and Hall 91:715 Sensitivity – Danielson and Stenseth 92:83

(3) Persistence: Persistence through time of an ecological system	Allen 83:4 Armstrong and McGhee 76:320 Botkin and Sobel 75:629 Connell and Sousa 83:791 DeAngelis and Waterhouse 87:7 Estberg and Patten 76:151 Harrison 79:660 Hastings 88:1666 Strong 90:421 Warner and Chesson 85:772 Yodzis 89:128	Stability – Begon et al. 90:792 Stability – Chesson and Huntly 89:293 Stability – Connell and Slatyer 77:1129 Stability – Crowley 92:246 Stability – Preston 69:7 Stability – Roff 74:246 Stability – Wu 76:156 Ecological stability – Nisbet and Gurney 82:10 Ecological stability – Wu 77:347 Essential stability – Wu 77:352 Existence – Bossel 92:267 Lagrange stability – Thornton and Mulholland 74:479 Mutual invasibility – Yodzis 89:128 Persistence at fixed densities – Armstrong and McGhee 76:319 Persistence in the wide sense – Royama 77:3 Permanence – Law and Blackford 92:568 Practical stability – Thornton and Mulholland 74:483 Strictly persistent – Royama 77:2 Strongly persistent – Li 88:353 Terminal stability – Wu 76:159 Total stability – Wu 76:159 Weakly persistent – Li 88:353
(4) Resistance: Staying essentially unchanged despite the presence of disturbances	Begon et al. 90:792 Boesch 74:109 Connell and Sousa 83:790 Gigon 83:98 Harrison 79:660 Harwell et al. 81:108 Kuss and Hall 91:715 Leps et al. 82:54 Steinman et al. 90:80	Stability – Hurd and Wolf 74:465 Stability – MacArthur 55:534 Stability – Margalef 68:12 Stability* – Remmert 89:286 Ecological stability – Mulholland 76:167 Ecological stability – Rutledge et al. 76:356 Inertia – Murdoch 70:500 Inertia – Orians 74:64 Inertia – Orians 75:141 Inertia – Westman 78:705 Malleability – Westman 91:213 Resilience – Holling 73:17 Resistance stability – Sutherland 90 Responsiveness – Roughgarden 75:6 Sensitivity – Estberg and Patten 76:152 Sensitivity* – Remmert 84:286 Vulnerability – Vincent and Anderson 79:218

Stability term and definition	Authors who use the term in the first column in more or less the same way	Terms with definitions mainly the same as in the first column
(5) Elasticity: Speed of return to the reference state (or dynamic) after a temporary disturbance	Connell and Sousa 83:790 Orians 74:64 Orians 75:141 Westman 78:706 Westman 91:213	Ecological stability – Danielson and Stenseth 92:38 Resilience – Begon et al. 90:792 Resilience – Carpenter et al. 92:784 Resilience – Crowley 92:247 Resilience – DeAngelis 80:764 Resilience – Hallet 91:384 Resilience – Harwell et al. 81:108 Resilience – Nakajima and DeAngelis 89:502 Resilience – Pimm 84:322 Resilience – Steinman et al. 90:80 Resilience – Steinman et al. 91:1299 Resiliency – Boesch 74:109
(6) Domain of attraction: The whole of states from which the reference state (or dynamic) can be reached again after a temporary disturbance	Holling 73:3 Pimm 84:322	Amplitude – Connell and Sousa 83:790 Amplitude – Orians 75:141 Amplitude – Westman 78:706 Amplitude – Westman 91:213 Attractor block – Armstrong and McGhee 76:320 Dynamic fragility – Begon et al. 90:792 Dynamic fragility – May 75:163 Dynamic robustness – Begon et al. 90:792 Dynamic robustness – Danielson and Stenseth 92:38 Dynamically bounded – Lewontin 69:18 Dynamic robustness – May 75:163 Elasticity – Ulrich 92:181 Repellor – Byers et al. 92:26 Semi-stable attractor – Byers et al. 92:25 Stable attractor – Byers et al. 92:10

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Ecosystems (2001) 4: 765–781
DOI: 10.1007/s10021-001-0045-9

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MINIREVIEW

From Metaphor to Measurement: Resilience of What to What?

Steve Carpenter,^{1*} Brian Walker,² J. Marty Anderies,² and Nick Abel²

¹Center for Limnology, 680 North Park Street, University of Wisconsin, Madison, Wisconsin 53706, USA; and ²CSIRO Sustainable Ecosystems, GPO Box 284, Canberra, ACT, 2615 Australia

Carpenter et al. (2001)

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MINIREVIEW

From Metaphor to Measurement: Resilience of What to What?

Dakos & Kéfi (2022)

Steve Carp

Environ. Res. Lett. 17 (2022) 043003

<https://doi.org/10.1088/1748-9326/ac5767>

¹Center for Limnology

ENVIRONMENTAL RESEARCH
LETTERS

TOPICAL REVIEW

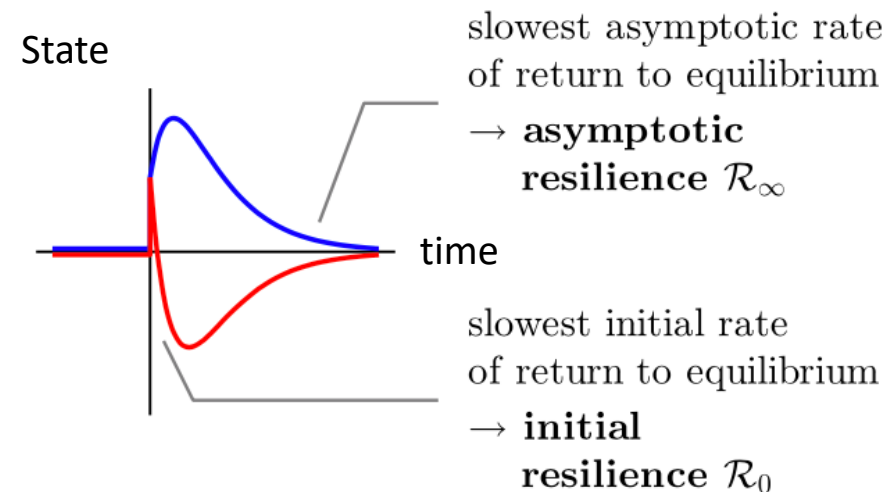
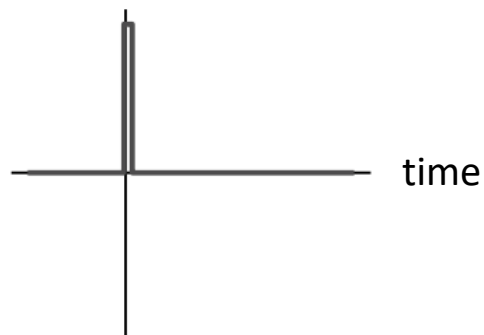
Ecological resilience: what to measure and how

Vasilis Dakos* and Sonia Kéfi

Two main definitions of resilience

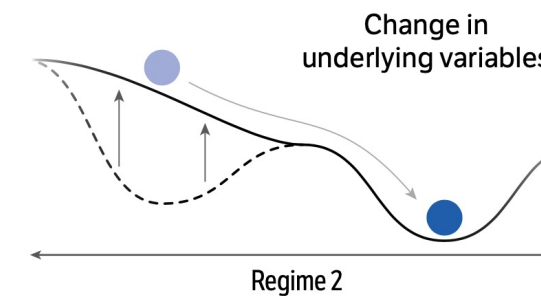
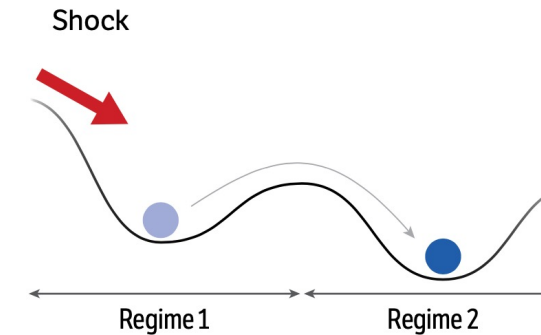
- Engineering resilience (Pimm, 1984)
 - Capacity of a system to bounce back to its initial state after a perturbation
 - Only one stable state (“equilibrium”), locally stable
 - Rather for small perturbations

Pulse perturbation



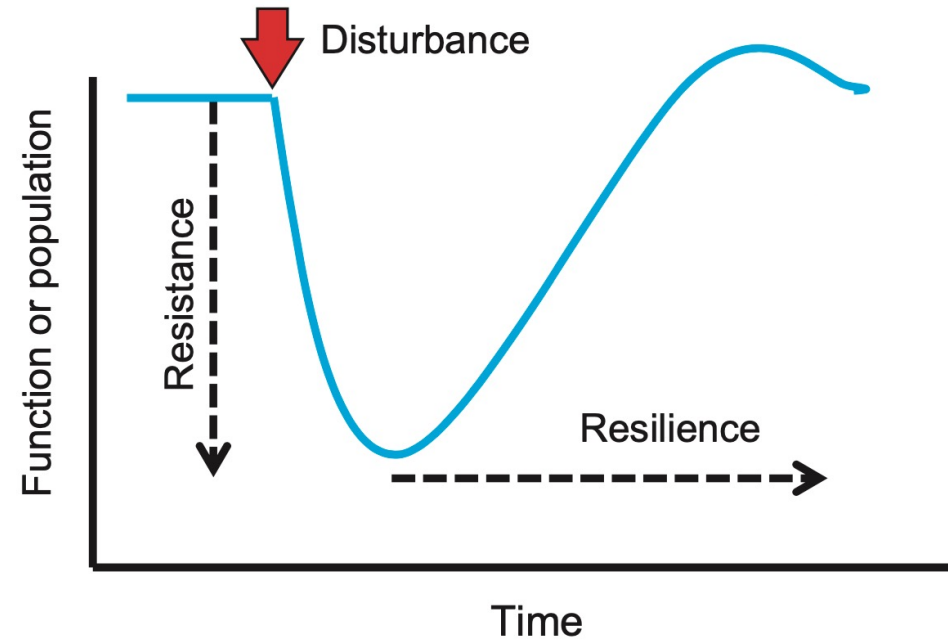
Two main definitions of resilience

- Ecological resilience (Holling, 1973; 1996)
 - Magnitude of disturbance that can be absorbed by an ecosystem, before it flips to an other state
 - Several alternative stable states
 - Adapted to large scale perturbations
 - Regime shifts/tipping points



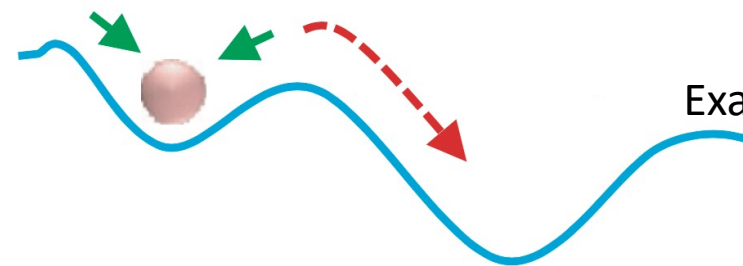
Two main definitions of resilience

Engineering resilience



Example: impact of a marine heat wave

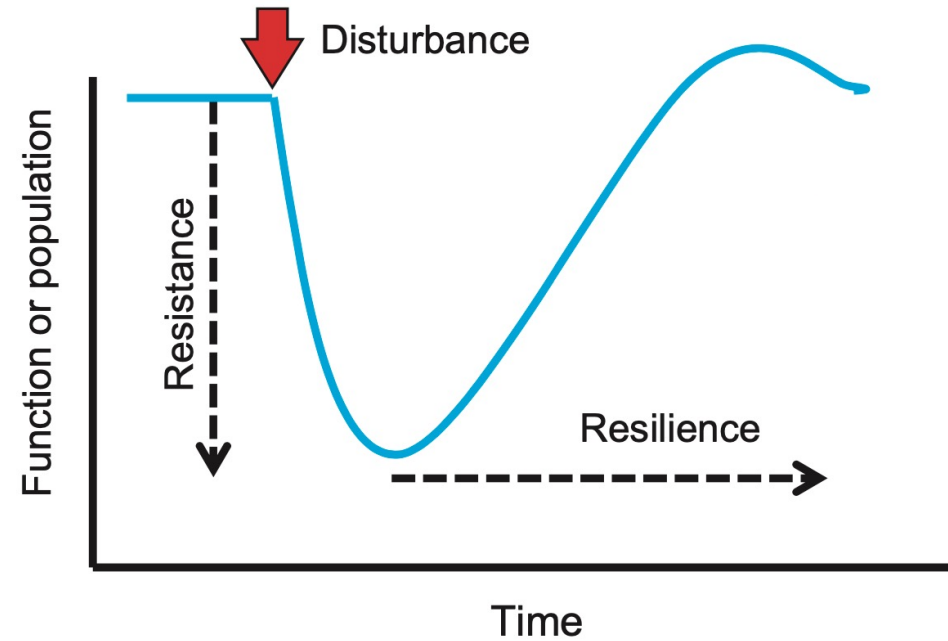
Ecological resilience



Example: impact of a tropical storm on a coral reef

Measuring resilience

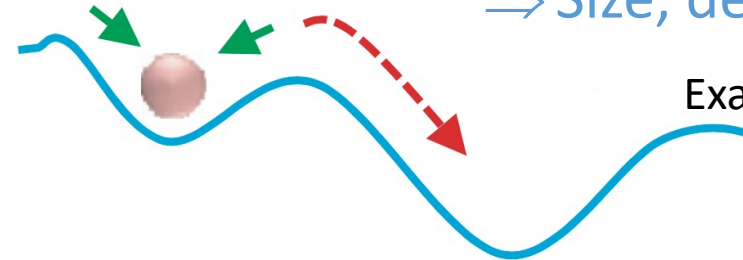
Engineering resilience



Example: impact of a marine heat wave

Asymptotic resilience R_∞
 \Rightarrow Long term return rate

Ecological resilience



More difficult to estimate in real life!

\Rightarrow Size, depth, slope of each basin of attraction

Example: impact of a tropical storm on a coral reef

Measuring resilience: various metrics!

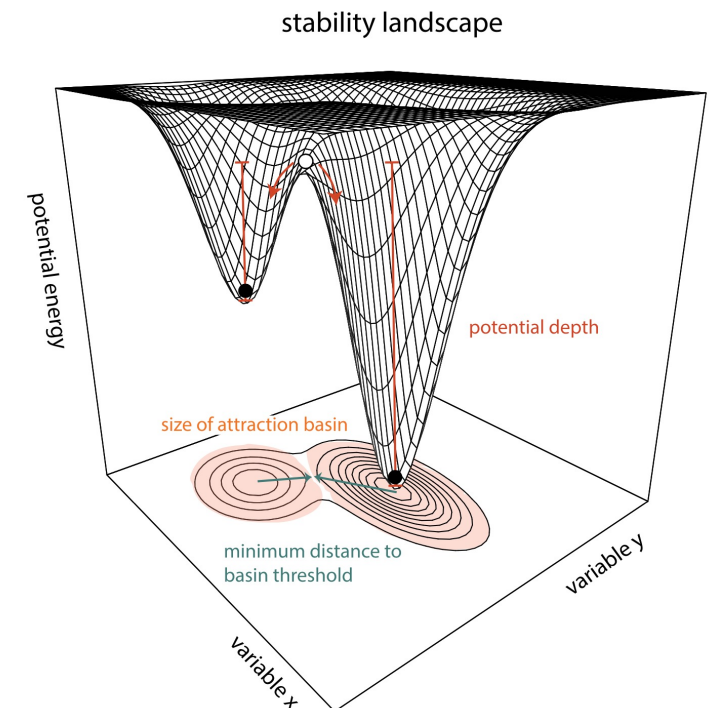
To list a few....

Engineering resilience
(local stability)

- Curvature of potential
- Variance
- Autocorrelation

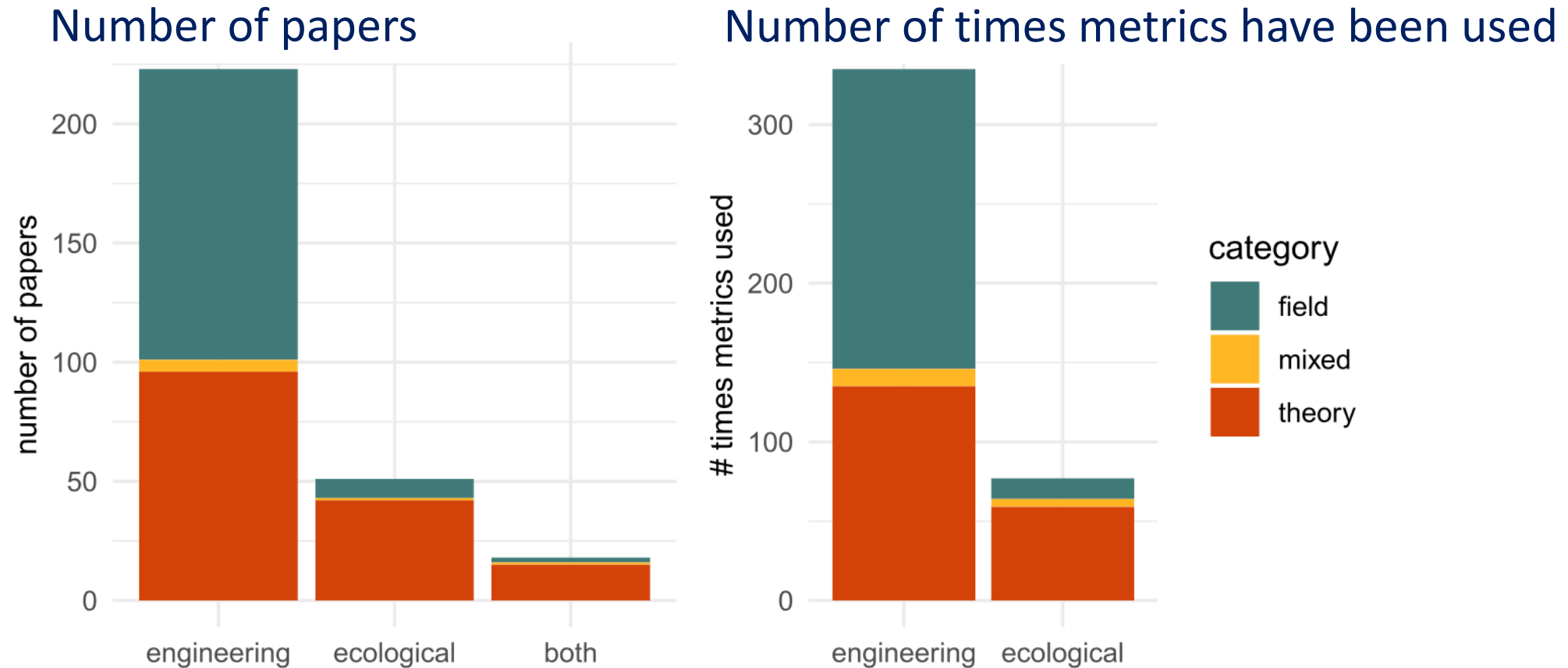
Ecological resilience
(non-local stability)

- Potential depth
- (min) distance to the basin threshold
- Size of the basin of attraction
- Skewness
- (mean) exit time to the alternative basin of attraction



Measuring resilience in practice?

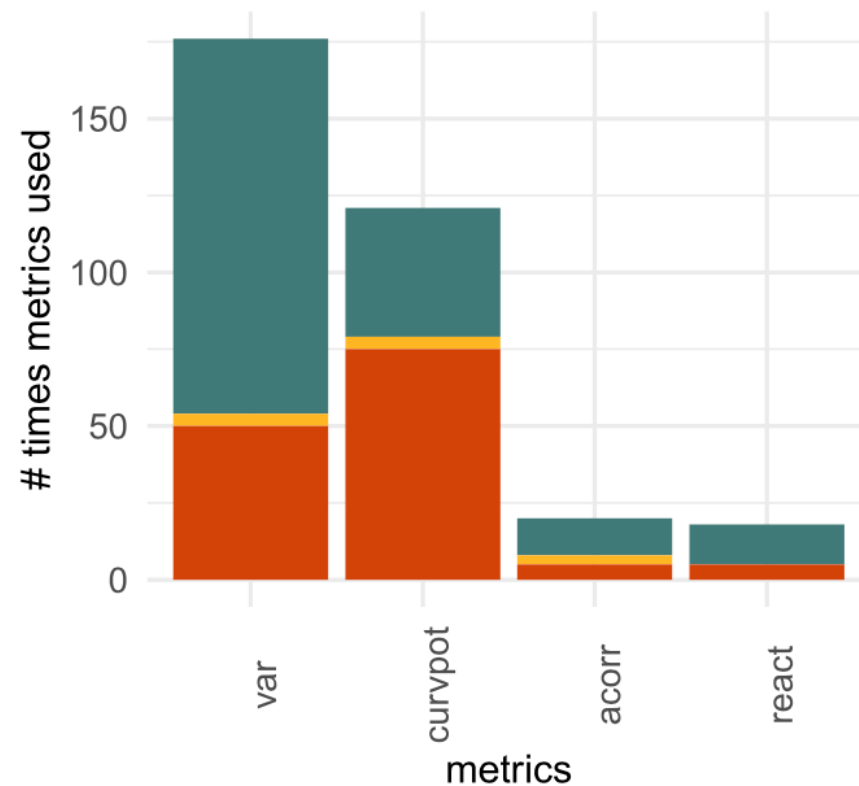
Bibliographic analysis from 459 papers (1950-2018)



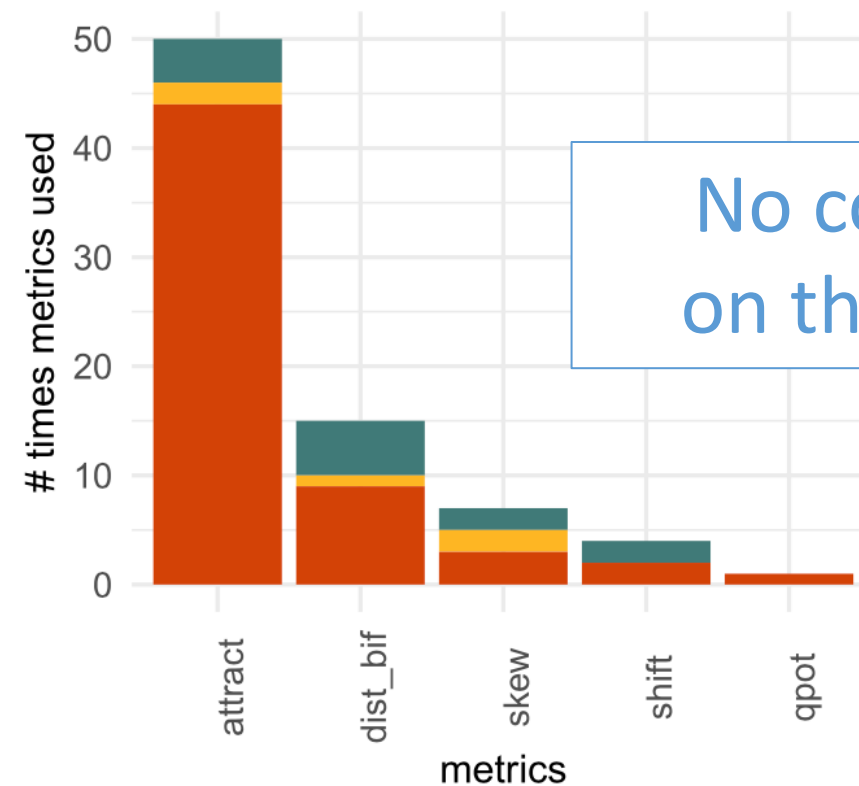
Measuring resilience in practice?

Bibliographic analysis from 459 papers (1950-2018)

Most commonly used metrics:
For engineering resilience



For ecological resilience

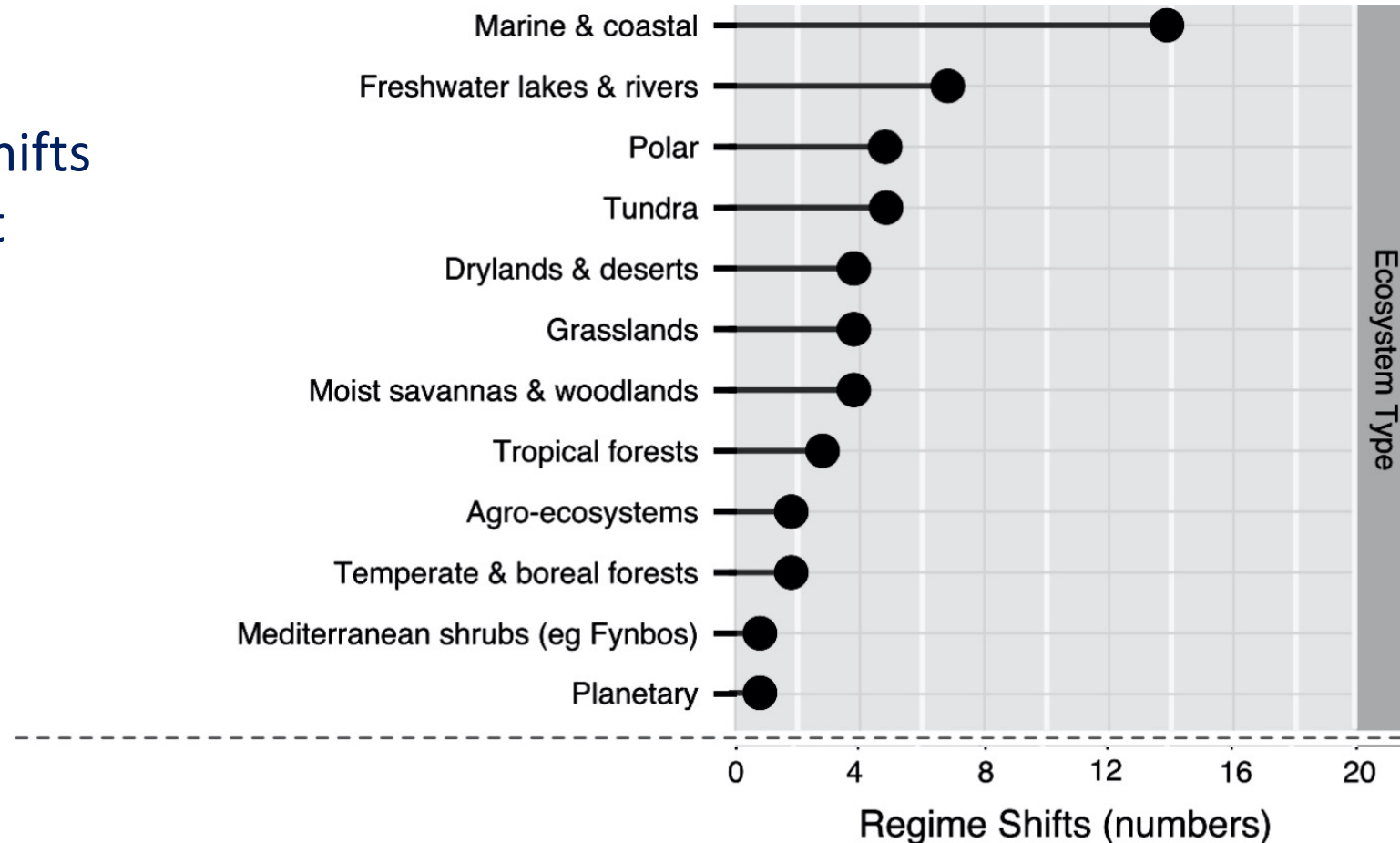


No consensus
on the metrics

Regime shifts in the stability landscape

Regime shifts = tipping points = switching from a stability valley to another

Number of regime shifts recorded in different ecosystem types



Marine regime shifts

Before

Tropical coral reef



Kelp forest



Coastal predatory fish



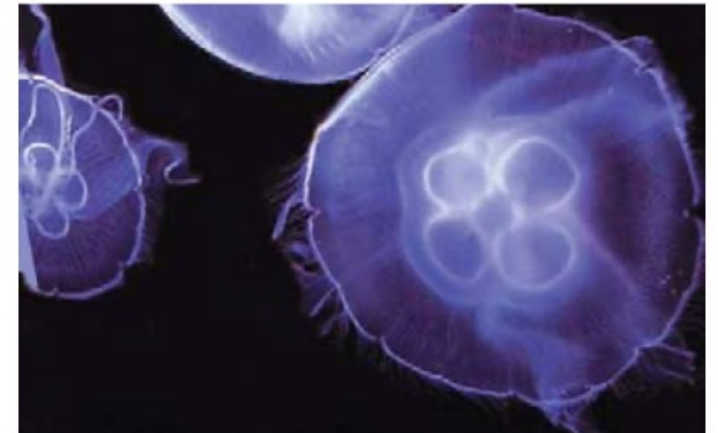
Degraded reef



Sea urchin barrens

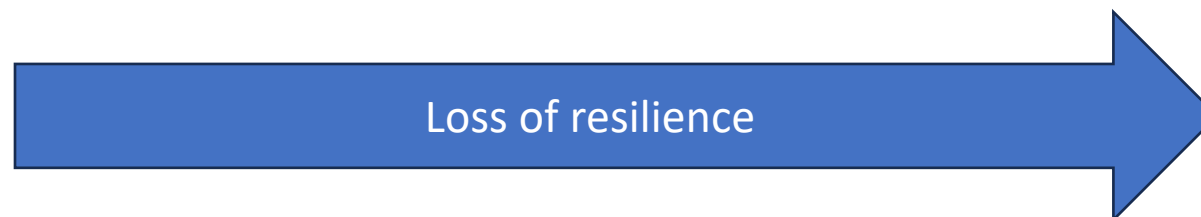
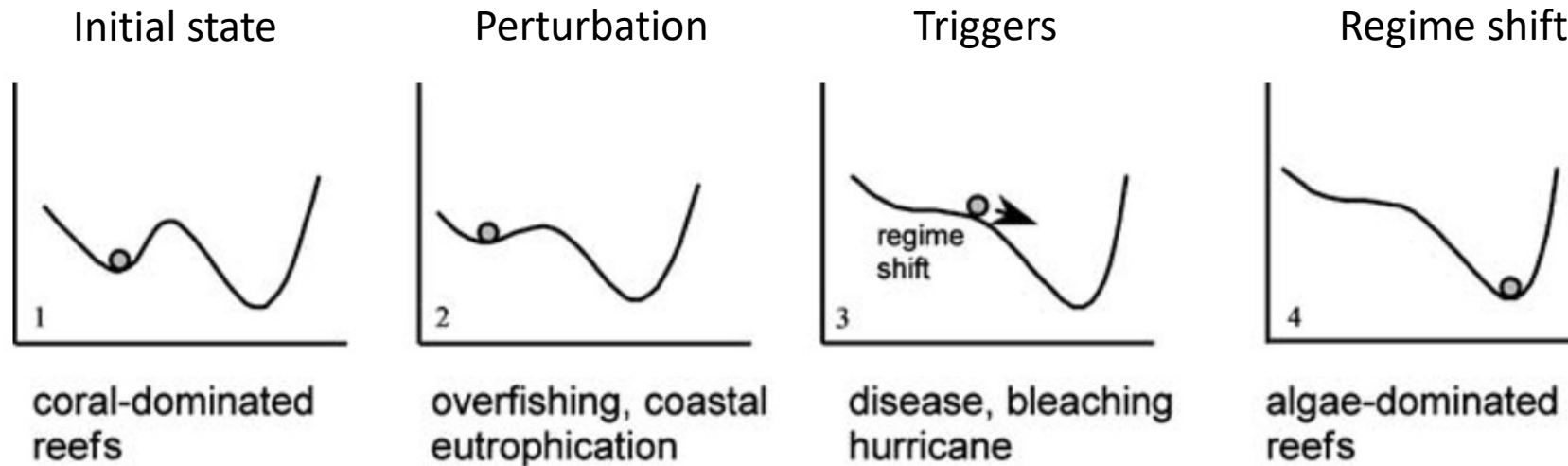


Overfished jellyfish-dominated

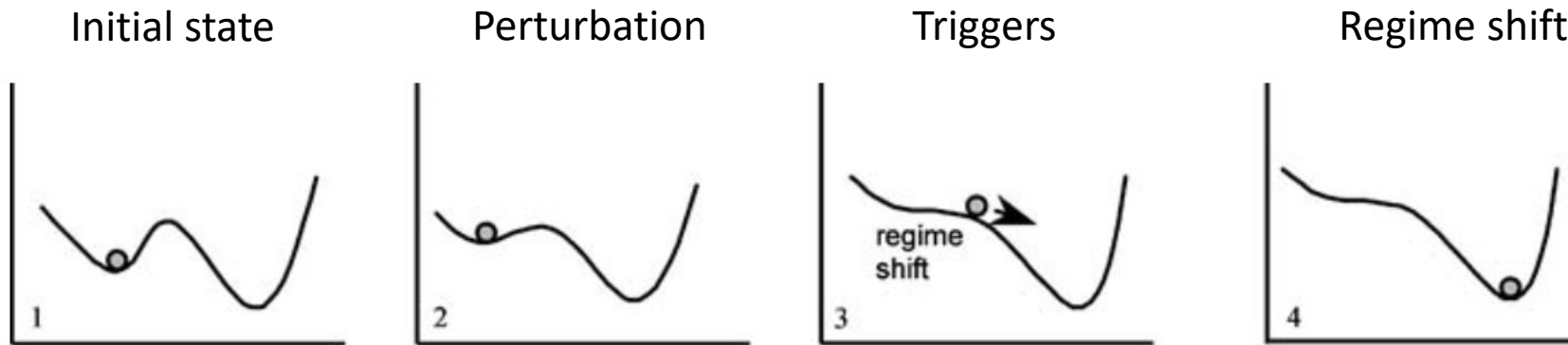


After

Marine regime shifts



Marine regime shifts



coral-dominated reefs

overfishing, coastal eutrophication

disease, bleaching hurricane

algae-dominated reefs

kelp forests

functional elimination of apex predators

thermal event, storm, disease,

sea urchin dominance

Loss of resilience



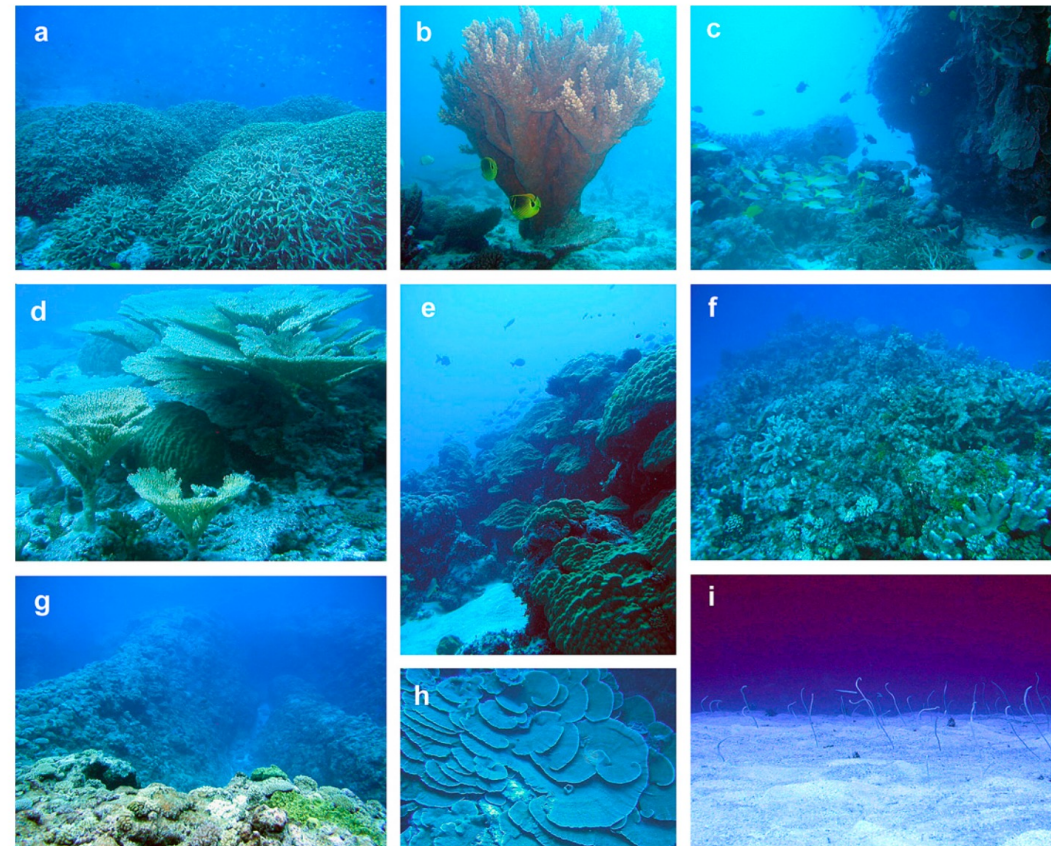
Examples of impressive resilience

- Recovery of coral reefs in the Marshall Islands after nuclear tests

Crater created during the nuclear tests in the 1950's



Bikini Atoll coral communities 2002



Enhancing resilience of socio-ecosystems

- Seven principles have been proposed:
 - 1) Maintain diversity and redundancy, e.g. protect species
 - 2) Manage connectivity between systems, e.g. between marine protected areas
 - 3) Manage slow variables and feedbacks, e.g., herbivorous species in coral reefs
 - 4) Foster an understanding of SES as complex adaptive systems, e.g. the large-scale rezoning of Australia's Great Barrier Coral Reef
 - 5) Encourage learning and experimentation
 - 6) Broaden participation, e.g., involved local fishermen and local populations
 - 7) Promote polycentric governance systems, e.g. failure when lack of institutions governing global marine fisheries