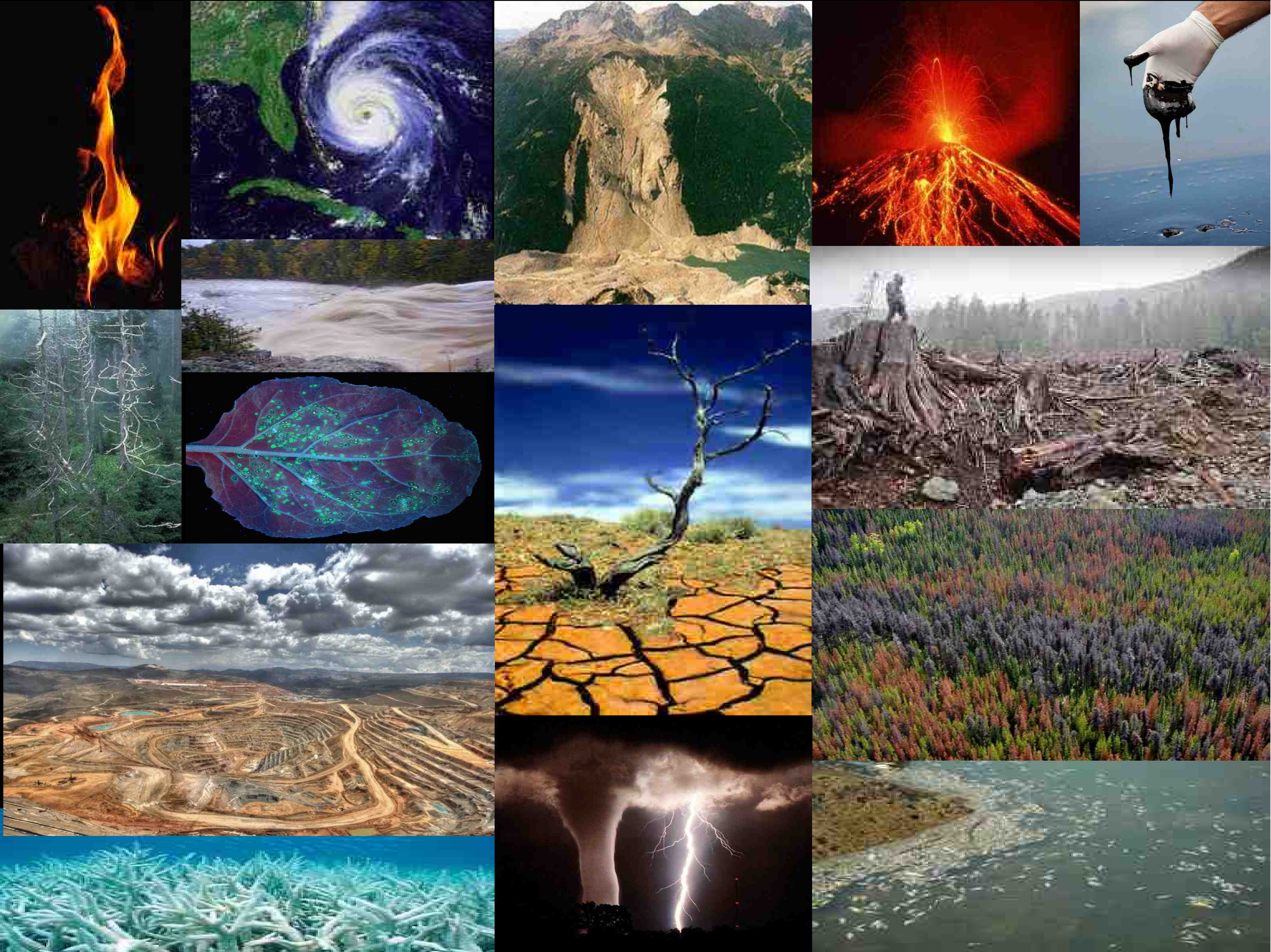
Ecosystem Resilience –

a 50 minute
(I promise that's quick)
summary

Nancy Shackelford, PhD Candidate
School of Environmental Studies



Some definitions

Grimm and Wissel. 1997: *Babel, or the ecological stability discussions: an inventory and analysis of terminology and a guide for avoiding confusion*

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
(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* – Zwölfer 78:15 Functional stability – Rejmánek 92:455 Perceived stability – Begon et al. 90:802 Persistence – Rahel 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 – Siljak 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 Species deletion stability – Pimm 80:142
(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 Responsivness – Roughgarden 75:6 Sensitivity – Estberg and Patten 76:152 Sensitivity* – Remmert 84:286 Vulnerability – Vincent and Anderson 79:218

Table 2 (continued)

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 Dynamical 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

Author	Definition	# Citations	Reference
1. Holling	A measure of the persistence of systems and of their ability to absorb change and disturbance and still maintain the same relationships between populations or state variables.	1743 294*	Holling 1973 Holling 1996
2. Gunderson	Property of an ecosystem that describes the change in stability (or return time) and resilience (the width of the stability domain).	281	Gunderson 2000
3. Walker	Resilience (the capacity of a system to absorb disturbance and reorganize while undergoing change so as to still retain essentially the same function, structure, identity, and feedbacks). Resilience has four components—latitude, resistance, precariousness, and panarchy—most readily portrayed using the metaphor of a stability landscape.	269	Walker et al. 2004
4. Carpenter	The rate at which a system returns to equilibrium after disturbance.	90	Carpenter et al. 1992
	The magnitude of disturbance that can be tolerated before a socio-ecological system moves to a difference region of a state space controlled by a different set of processes, including the degree to which the system is capable of self-organization, and how much it expresses a capacity for learning and adaptation.	341	Carpenter et al. 2001
5. Pimm	How fast a variable that has been displaced from equilibrium returns to it. Resilience could be estimated by a return time: the amount of time taken for the displacement to decay to some specified fraction of its initial value.	1659*	Pimm 1991

Myers-Smith, *et al*. 2012. *Resilience: Easy to use but hard to define*

Ok, never mind. Let's start at the beginning

Professor C.S. (Buzz) Holling

RESILIENCE AND STABILITY OF ECOLOGICAL SYSTEMS ◆ 4050

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INTRODUCTION

Individuals die, populations disappear, and species become extinct. That is one view of the world. But another view of the world concentrates not so much on presence or absence as upon the numbers of organisms and the degree of constancy of their numbers. These are two very different ways of viewing the behavior of systems and the usefulness of the view depends very much on the properties of the system concerned. If we are examining a particular device designed by the engineer to perform specific tasks under a rather narrow range of predictable external conditions, we are likely to be more concerned with consistent nonvariable performance in which slight departures from the performance goal are immediately counteracted. A quantitative view of the behavior of the system is, therefore, essential. With attention focused upon achieving constancy, the critical events seem to be the amplitude and frequency of oscillations. But if we are dealing with a system profoundly affected by changes external to it, and continually confronted by the unexpected, the constancy of its behavior becomes less important than the persistence of the relationships. Attention shifts, therefore, to the qualitative and to questions of existence or not.

Our traditions of analysis in theoretical and empirical ecology have been largely inherited from developments in classical physics and its applied variants. Inevitably, there has been a tendency to emphasize the quantitative rather than the qualitative, for it is important in this tradition to know not just that a quantity is larger than another quantity, but precisely how much larger. It is similarly important, if a quantity fluctuates, to know its amplitude and period of fluctuation. But this orientation may simply reflect an analytic approach developed in one area because it was useful and then transferred to another where it may not be.

Our traditional view of natural systems, therefore, might well be less a meaningful reality than a perceptual convenience. There can in some years be more owls and fewer mice and in others, the reverse. Fish populations wax and wane as a natural condition, and insect populations can range over extremes that only logarithmic

'Ecological' resilience: “a measure of the persistence of systems and of their ability to absorb change and disturbance and still maintain the same relationships between populations or state variables”


NATIONAL GEOGRAPHIC
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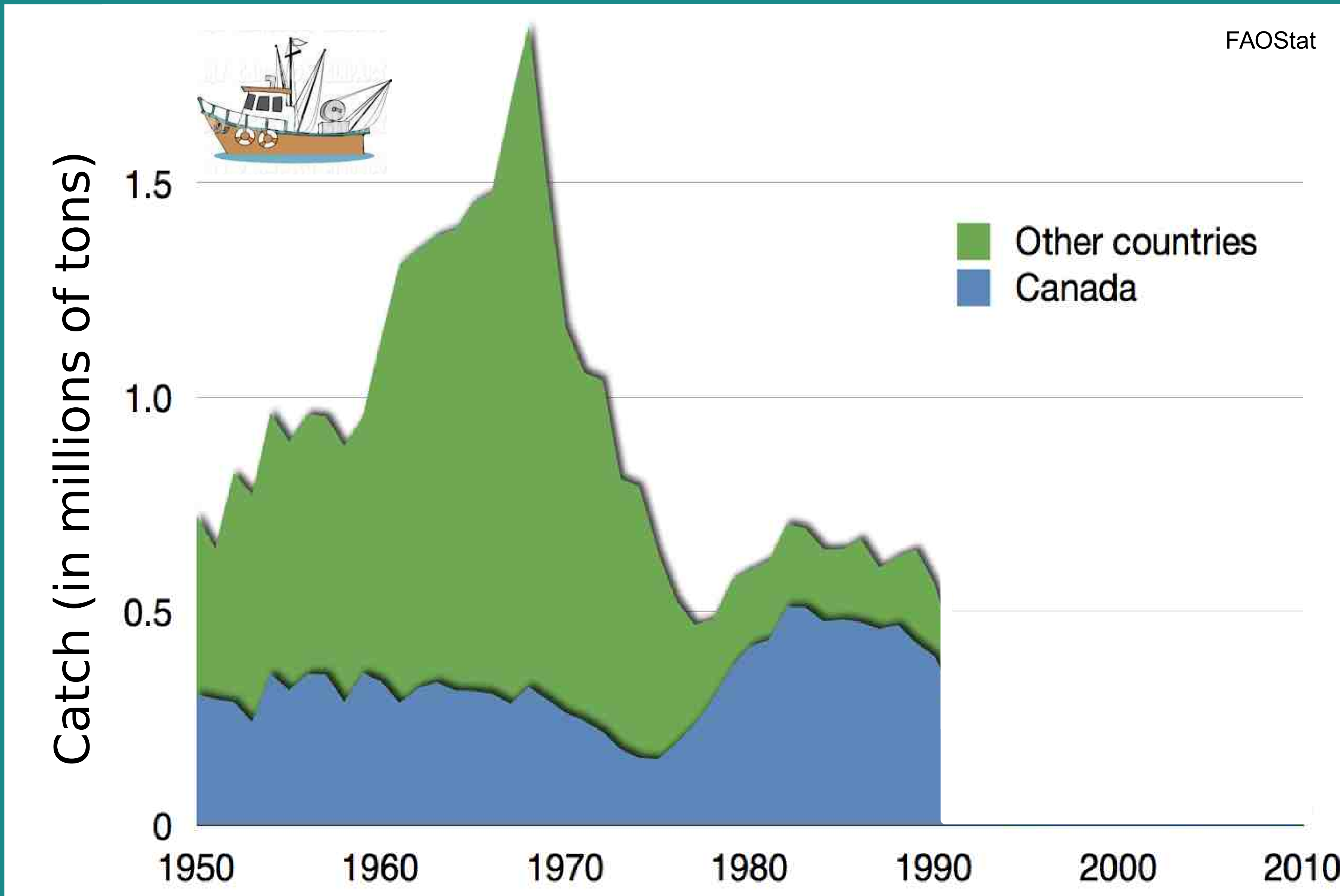
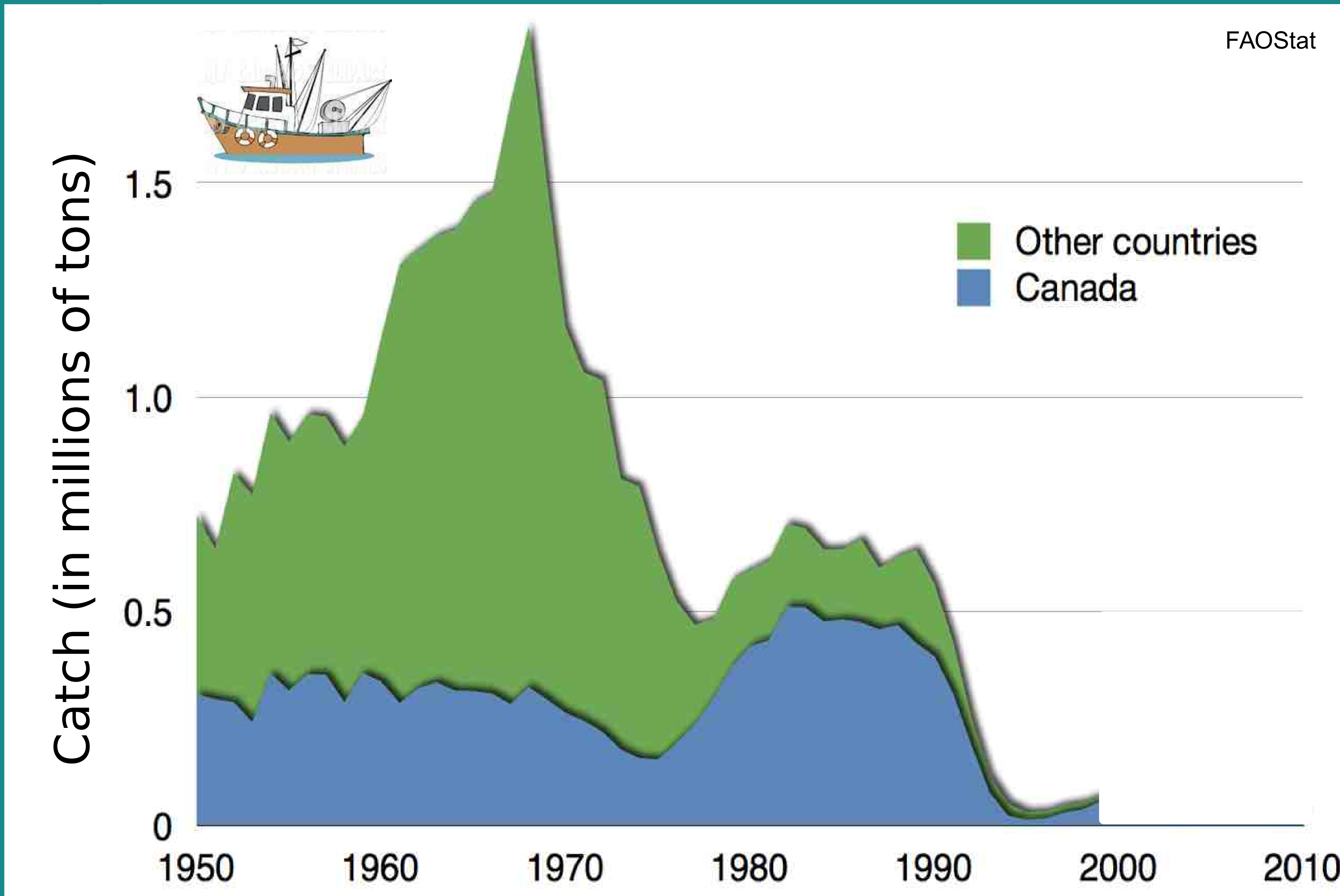


North Atlantic Cod collapse of 1992



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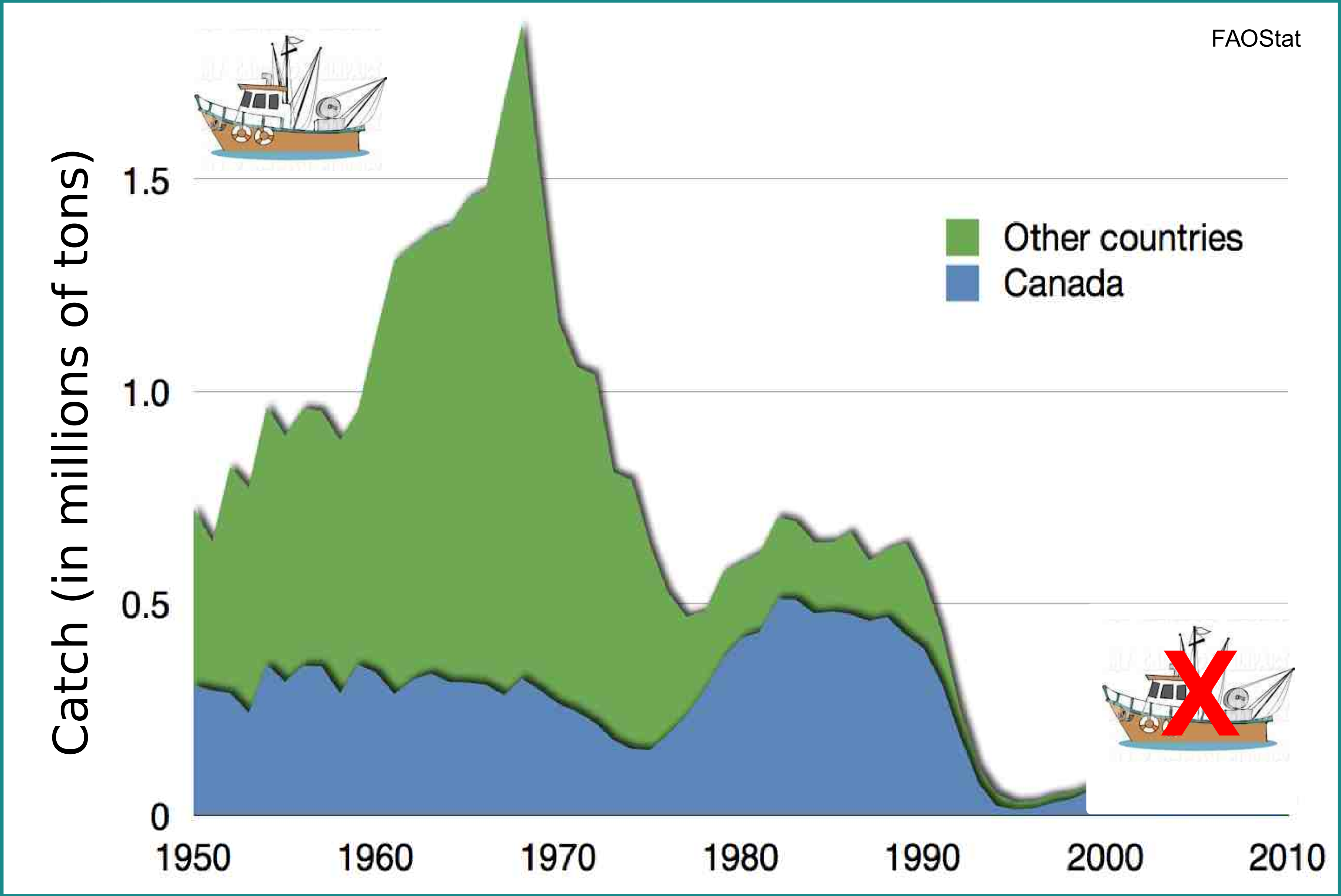
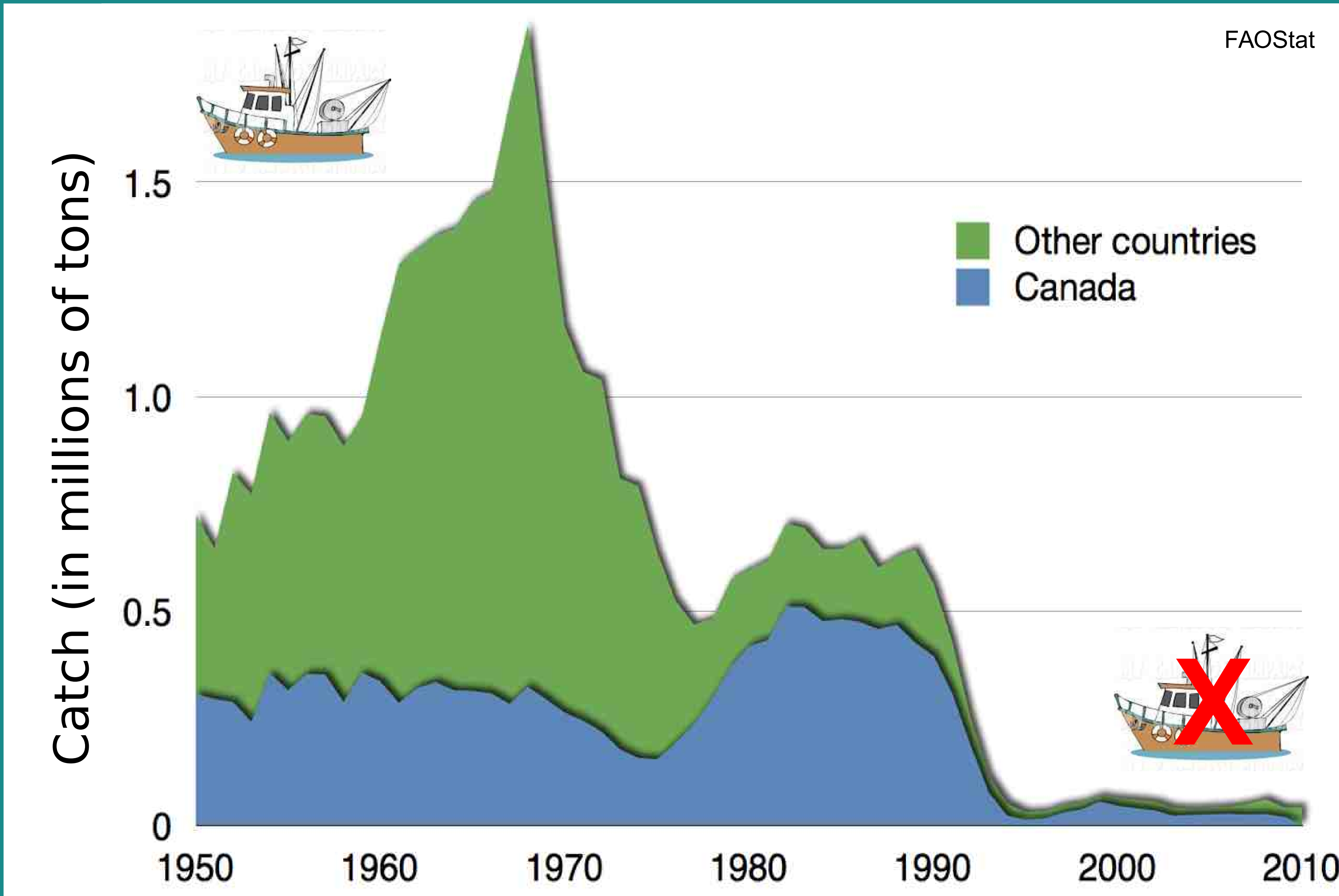


North Atlantic Cod collapse of 1992



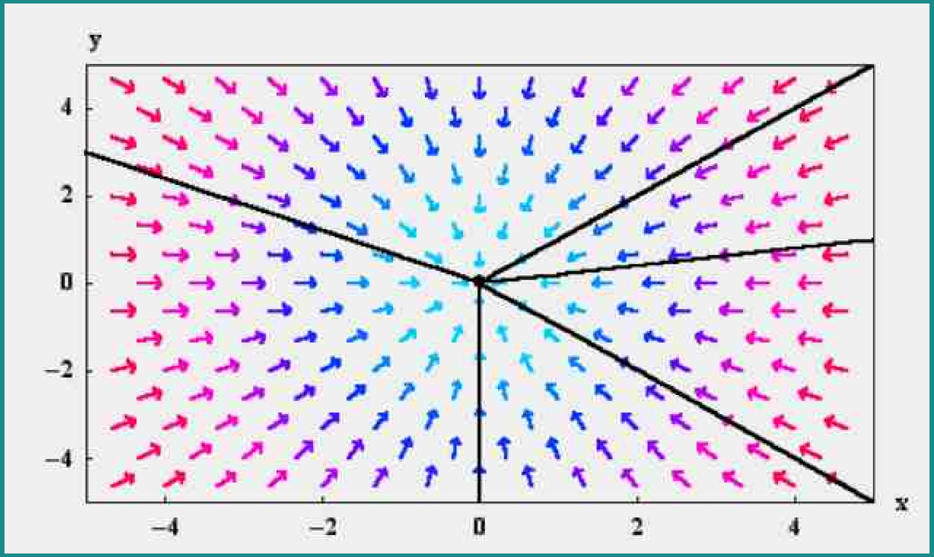
North Atlantic Cod collapse of 1992


Brocken Inaglory

Linda Pitkin

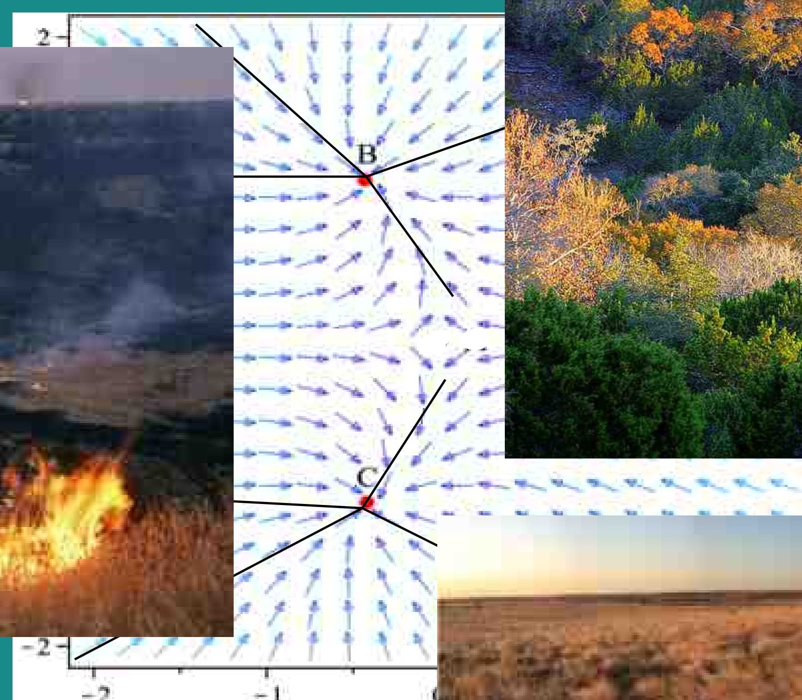
Revolution!

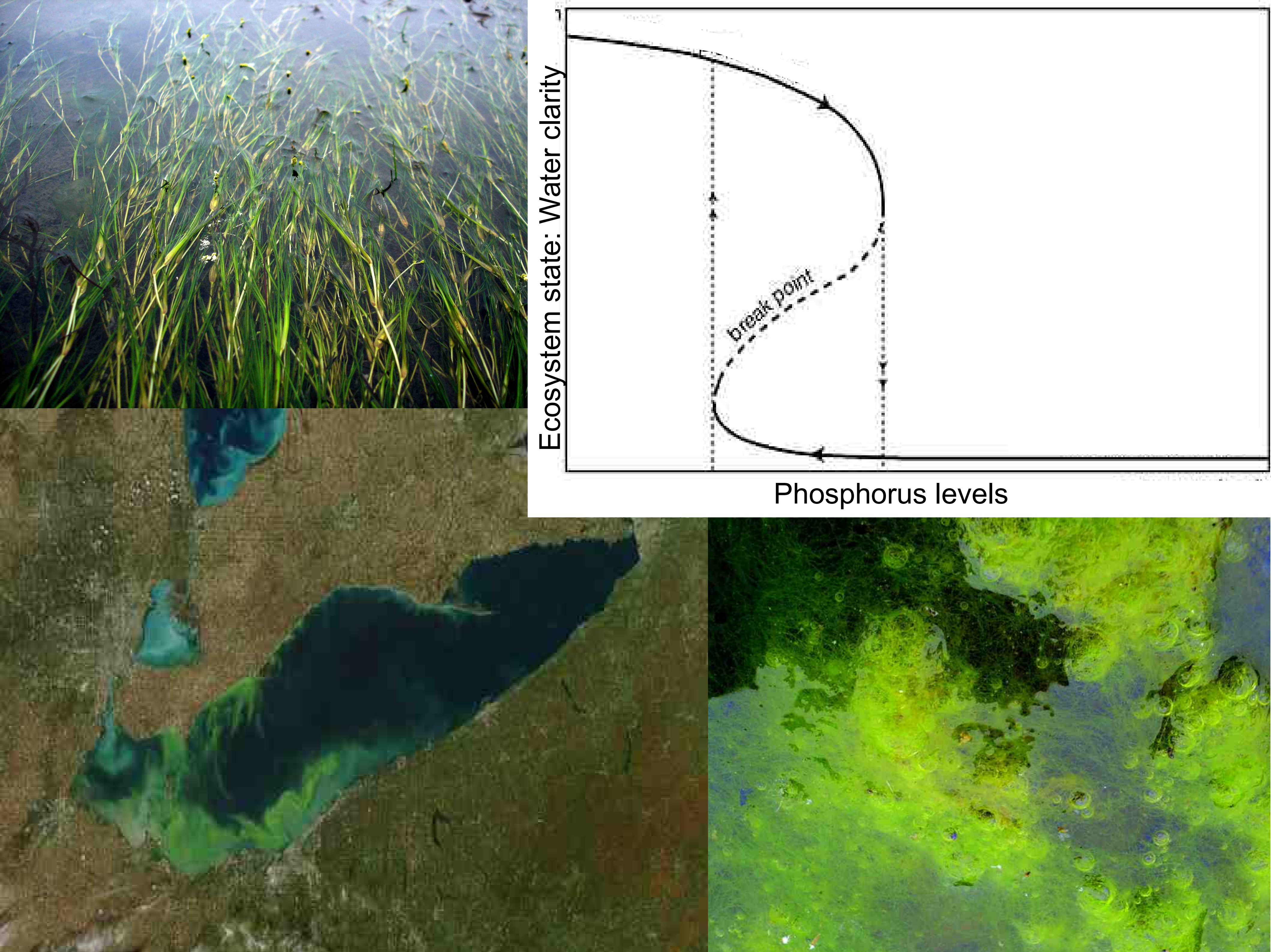
The idea that there is a 'balance of nature' is commonly held by biologists. They feel that the organisms in a community are harmoniously adjusted to one another so that a state of dynamic equilibrium exists. In this equilibrium the numbers of individuals of each species in the community remain relatively constant and significant changes in numbers occur only when something upsets the natural “balance”. (Ehrlich and Birch, 1967)



Alternative stable states

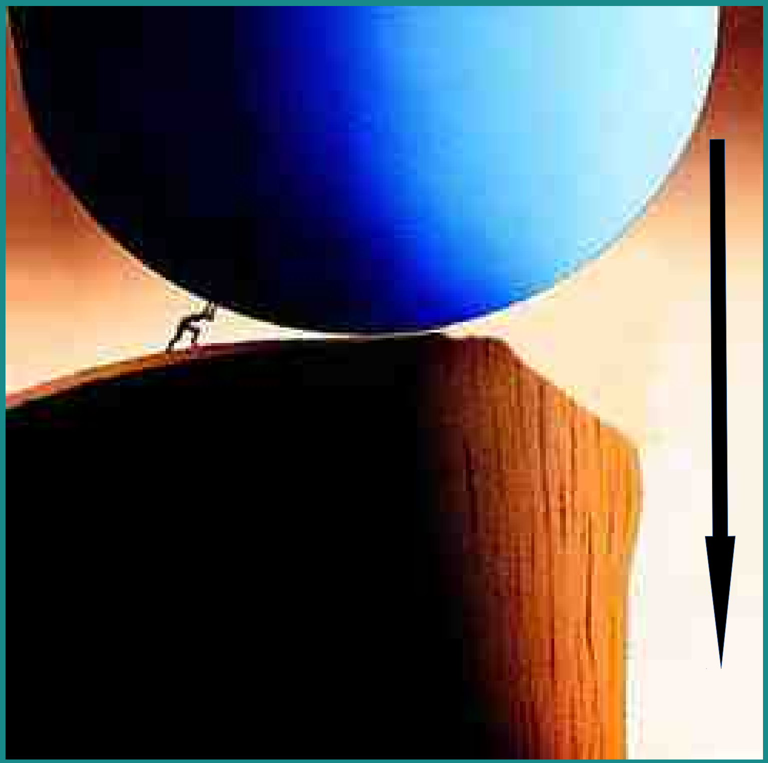
The theory that ecological systems may exist potentially indefinitely in contrasting states under the same external environmental conditions

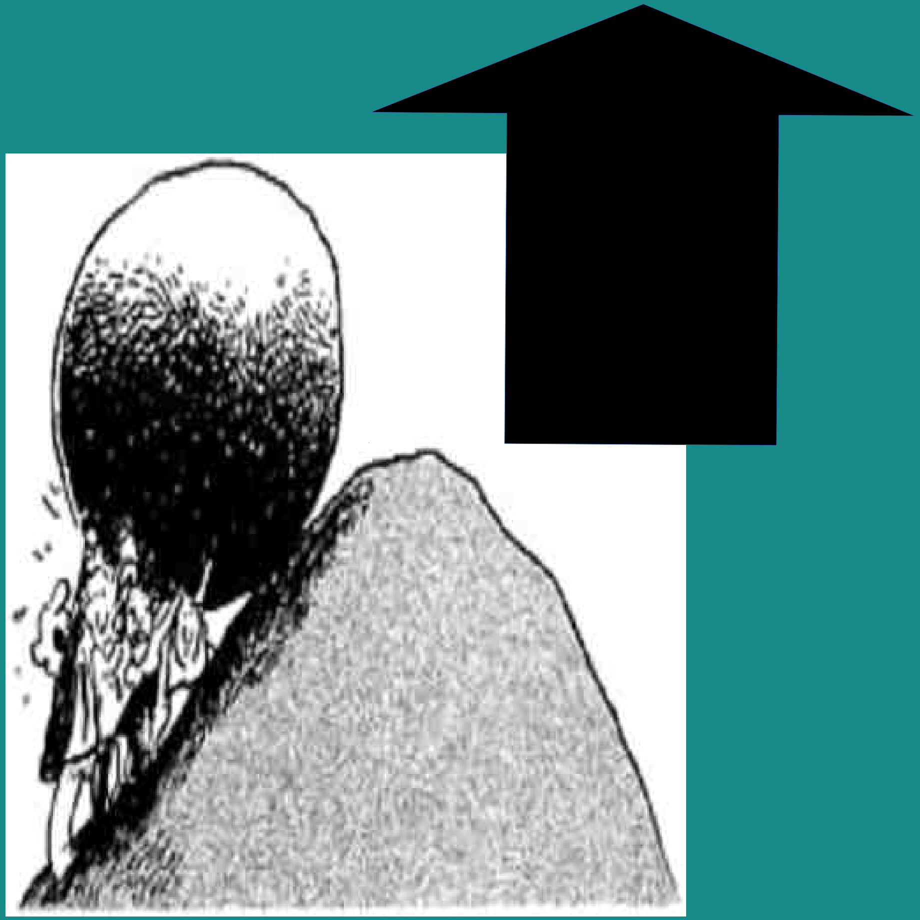




Ecosystem state: Water clarity
break point
Phosphorus levels

Hysteresis



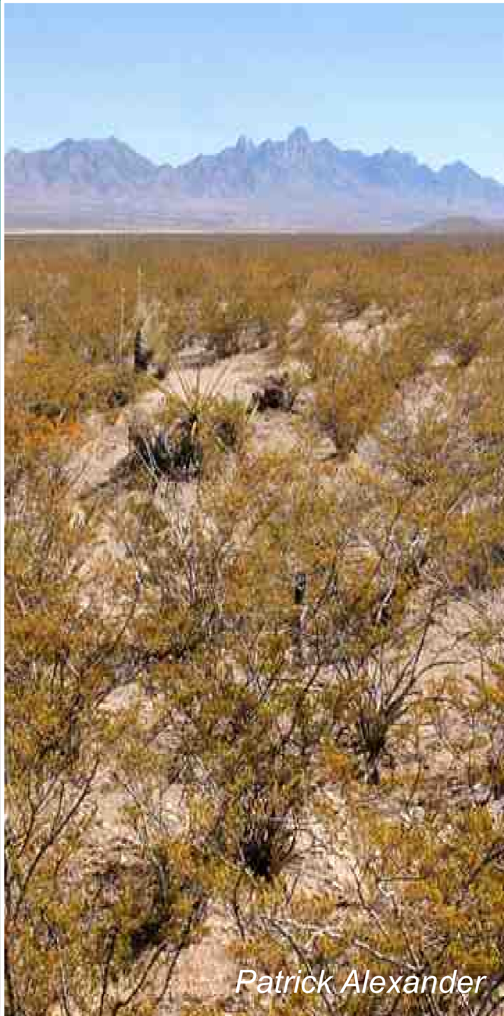


'Ecological' resilience – which ecosystems are more resilient? Which are less? How do we predict?

Mechanisms

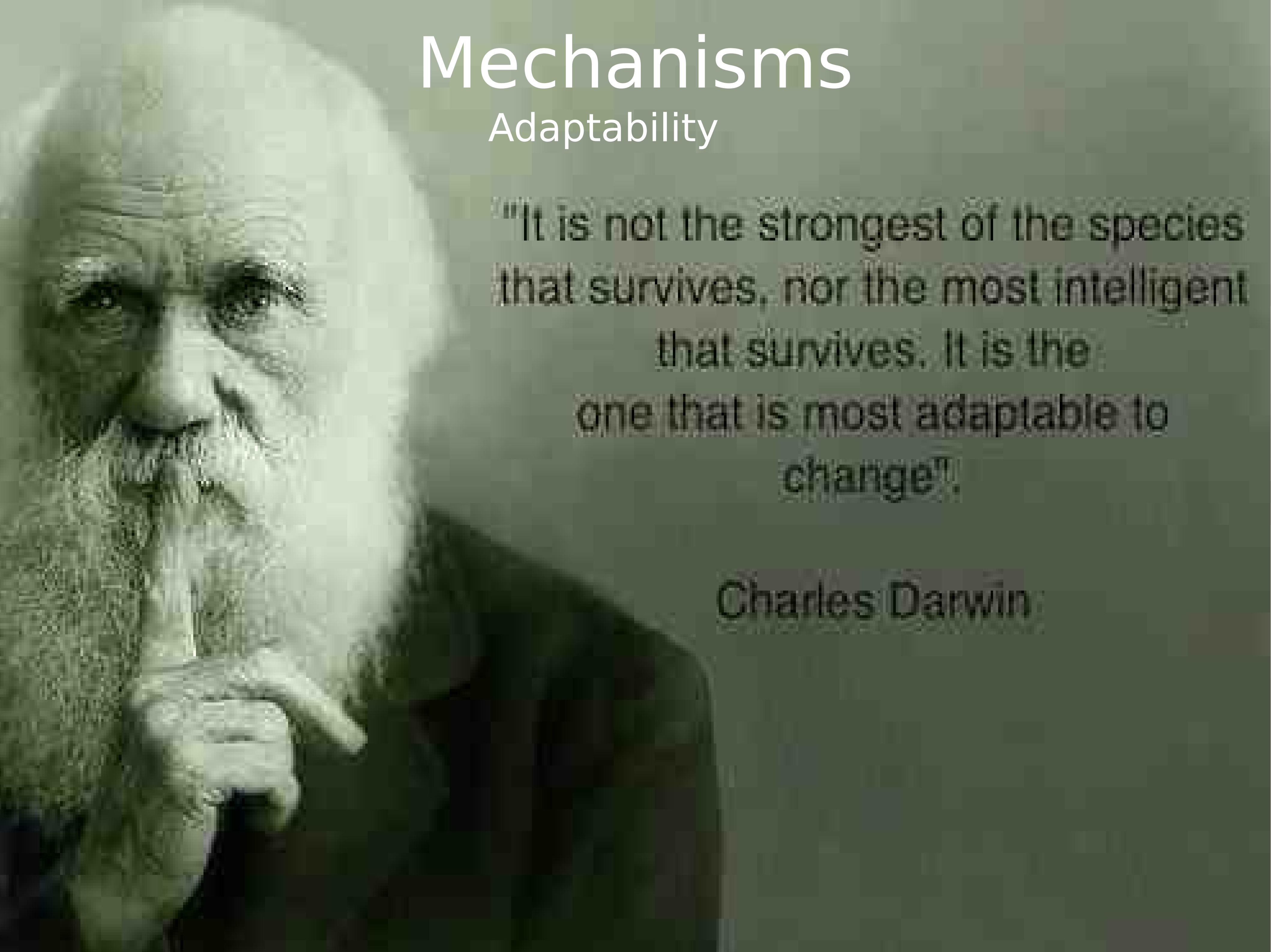
Ecosystem and disturbance-specific mechanisms

(..resilience *of* what *to* what?)



Mechanisms

Adaptability



Vol. 121, No. 6 The American Naturalist June 1983

ON THE EVIDENCE NEEDED TO JUDGE ECOLOGICAL STABILITY OR PERSISTENCE

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Submitted September 17, 1981; Revised October 14, 1982; Accepted November 4, 1982

"The balance of nature has been a background assumption in natural history since antiquity" (Egerton 1973, p. 322). This continues to be true today; some modern field ecologists, assuming that natural ecosystems are stable, have applied ideas of mathematical stability theory to the actual communities they are studying. We believe that, before one applies such theory to a natural population or community, one should first decide whether or not it is stable. Our aim here is to describe the sorts of evidence one would need to obtain from natural populations or communities in order to decide whether they are stable or persistent, as defined below. One aspect we shall stress in particular is whether any given real community exists in multiple stable states in different places at the same time or in the same place at different times (Sutherland 1974).

When considering changes in natural populations and communities, it is important to distinguish between two viewpoints. As Holling (1973) has pointed out, one view is concerned with the degree of constancy in the numbers of organisms. With this view, stability is the property of interest. In contrast is the view that concentrates, not on constancy of numbers, but on presence or absence. He states (1973, p. 1): "If we are dealing with a system profoundly affected by changes external to it, and continually confronted by the unexpected, the constancy of its behavior becomes less important than the persistence of the relationships. Attention shifts, therefore, to the qualitative and to questions of existence or not."

Past discussions of stability have sometimes confused these two viewpoints and have also applied identical terms to both. Therefore we would like first to define and discuss the terms we will use in this paper, as well as those previously used. Some of these terms have also been applied by theoretical and mathematical workers to model ecosystems under particular specified assumptions. We want to emphasize that our usage applies not to these models but only to the real world. We are not interested in testing the assumptions of these models, nor in using them to interpret data from actual ecosystems. We do not seek to contribute here

* Order of authorship decided by flip of a coin.
Address reprint requests to W. Sousa.

Am. Nat. 1983. Vol. 121, pp. 789–824.

1. Remains at state when disturbed or returns after disturbance

2. Remains at state either for one full generation time for all organisms OR a time length such that replacement of all organisms has ocurred (as juveniles)

3. Exists under same physical conditions as alternative state

Recovery


NATURE VOL. 307 26 JANUARY 1984 — REVIEW ARTICLE

The complexity and stability of ecosystems

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Early studies suggested that simple ecosystems were less stable than complex ones, but later came to the opposite conclusion. Confusion arose because of the many different meanings o plexity' and 'stability'. Most of the possible questions about the relationship between st complexity have not been asked. Those that have yield a variety of answers.

ELTON[1] noted the dangers of human simplification of the natural environment if ecosystems become less stable as they become more simple. The consequence may be increasingly

in the discussion of stability–complexity relationships. question has logical supremacy.

Definitions

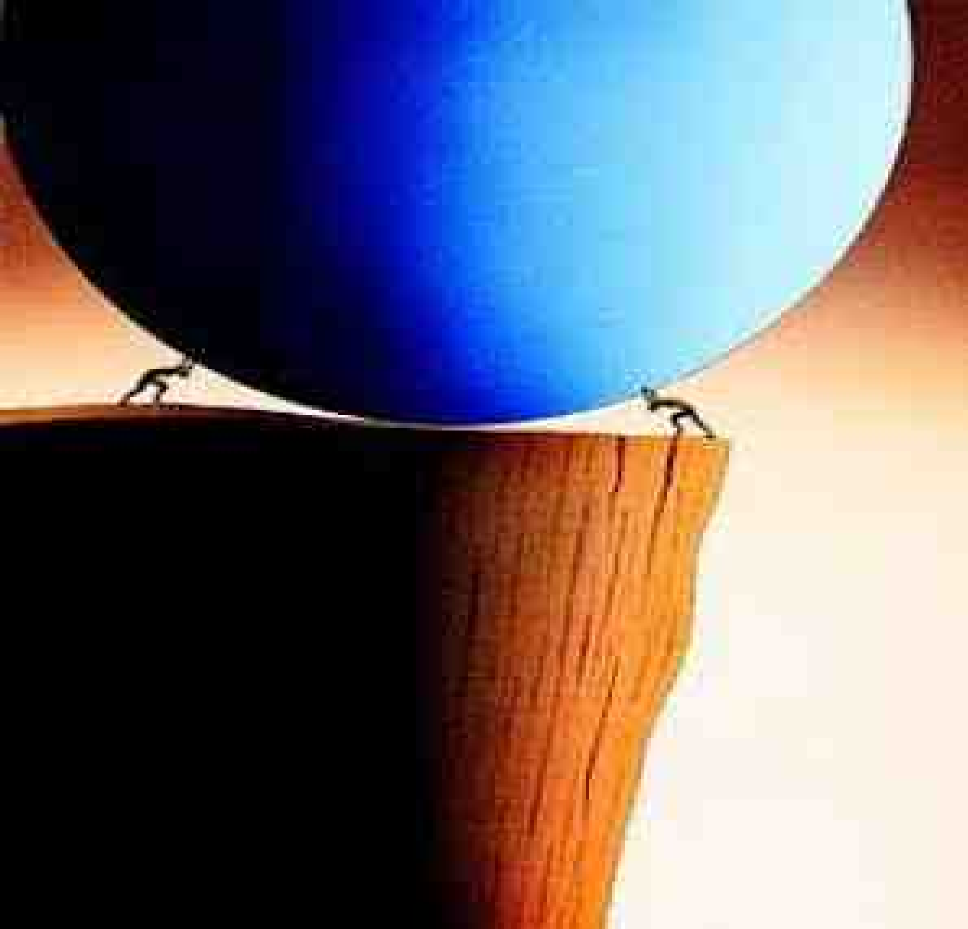
'Engineering resilience': "How fast the variables return towards their equilibrium following a perturbation. Resilience is not, therefore, defined for unstable systems.

Mechanisms

Functional redundancy

Mechanisms

Landscape context



Resistance

the degree to which a variable is changed following a perturbation

Mechanisms

Response diversity

Mechanisms
Spatial configuration

Press

Pulse


Biodiversity


Landscape context
Gerry Ellis

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

ECOSYSTEMS

MINIREVIEW

From Metaphor to Measurement: Resilience of What to What?

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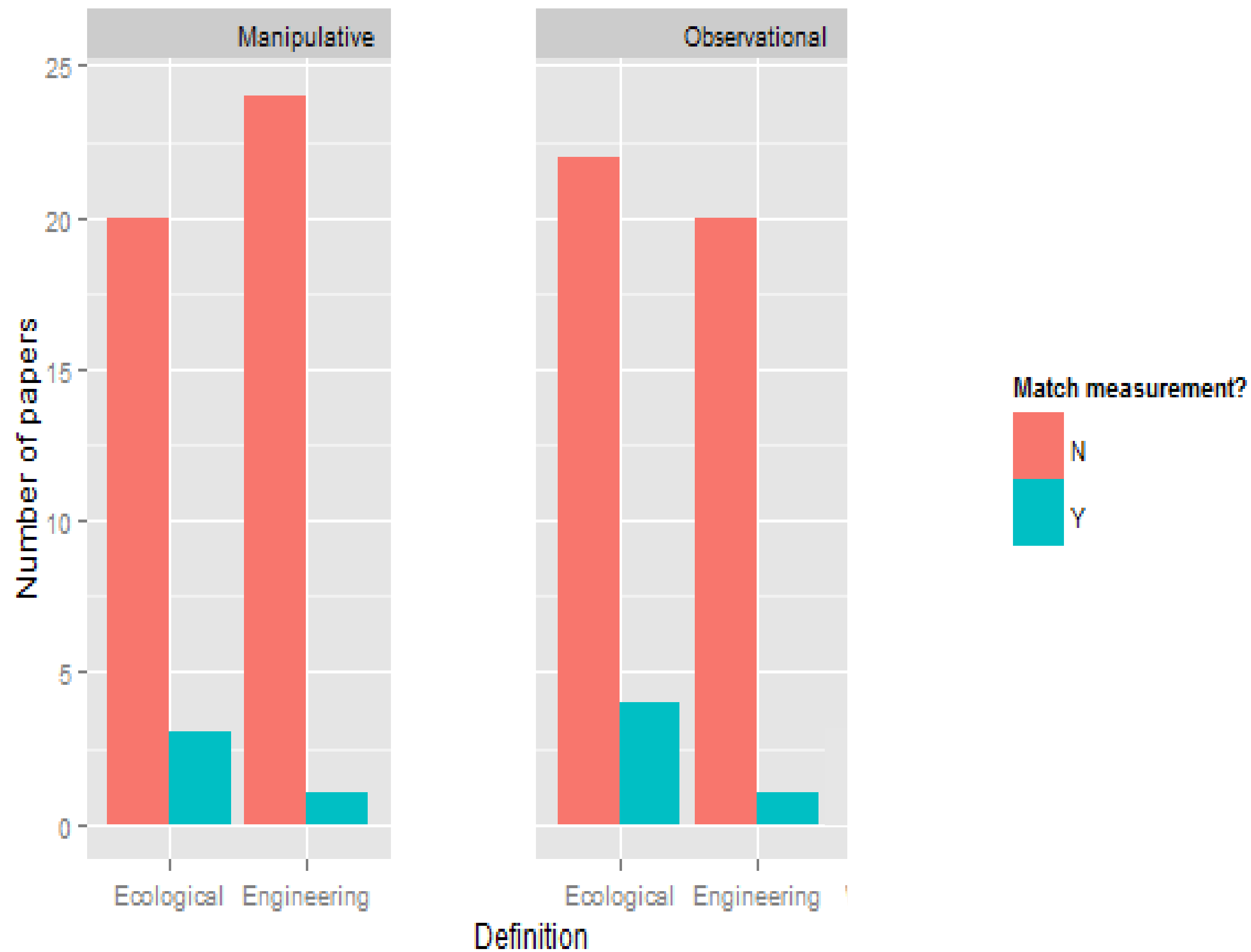
Abstract

Resilience is the magnitude of disturbance that can be tolerated before a socioecological system (SES) moves to a different region of state space controlled by a different set of processes. Resilience has multiple levels of meaning: as a metaphor related to sustainability, as a property of dynamic models, and as a measurable quantity that can be assessed in field studies of SES. The operational indicators of resilience have, however, received little attention in the literature. To assess a system's resilience, one must specify which system configuration and which disturbances are of interest. This paper compares resilience properties in two contrasting SES, lake districts and rangelands, with respect to the following three general features: (a) The ability of an SES to stay in the domain of attraction is related to slowly changing variables, or slowly changing disturbance regimes, which control the boundaries of the domain of attraction or the frequency of events that could push the system across the boundaries. Examples are soil phosphorus content in lake districts woody vegetation cover in rangelands, and property rights systems that affect land use in both lake districts and rangelands. (b) The ability of an SES to self-organize is rela
reorganization is endogen
external drivers. Self-org
coevolved ecosystem com
of social networks that fac
solving. (c) The adaptive
lated to the existence of n
tion of novelty or learning
versity at multiple scal
institutions that facilitate
ery, and innovation.

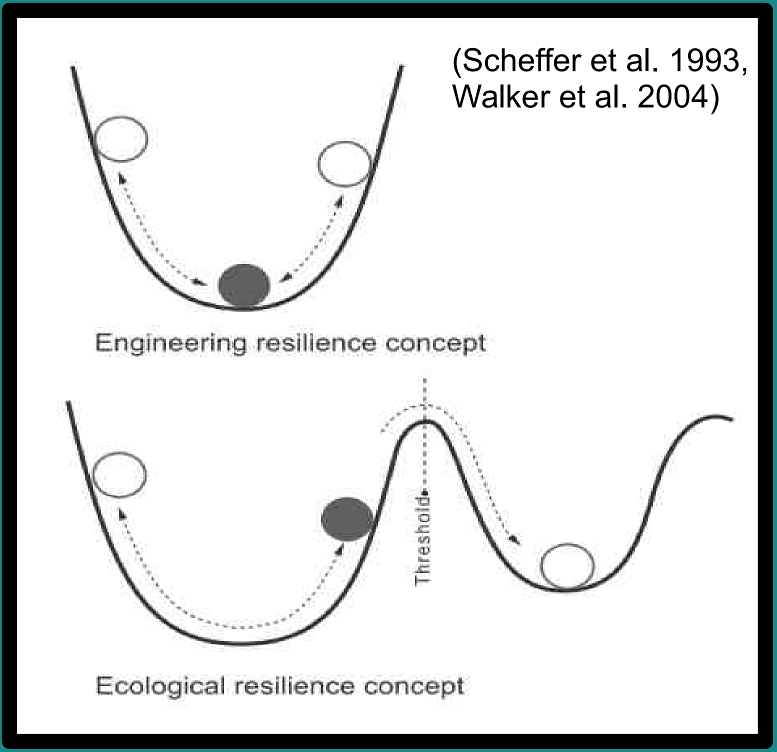
Key words: resilience; r
tence; socioecological sys
rangelands; sustainability
tive capacity; adaptive cy

Introduction

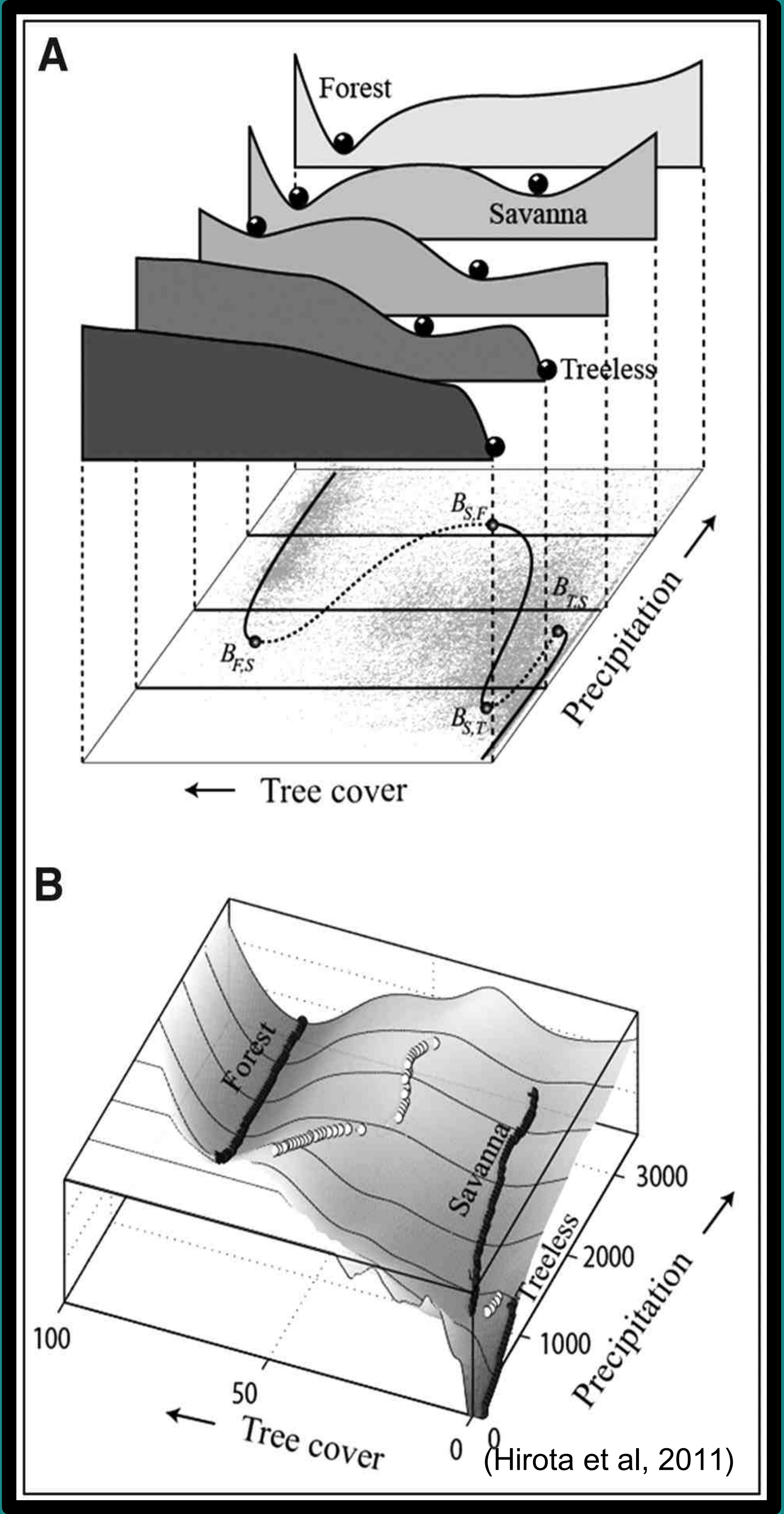
In the rapidly developing area of research on ecosystem services and the people who depend on them, the term "resilience" is often used to describe the characteristic features of a system that are related to sustainability. As a technical term, the idea of "resilience" originated in the field of ecology (Holling 1973). Diverse definitions of resilience and other concepts related to stability can be found in McCoy 1993). The concep
in a great variety of int
cerned with the interacti
nature (see, for example
1995; Hanna and others
1997; Berkes and Folke 1
and Nichols 1999; Kinzig
son 2000; Gunderson and
silience" and "sustainabil
tiple levels of meaning

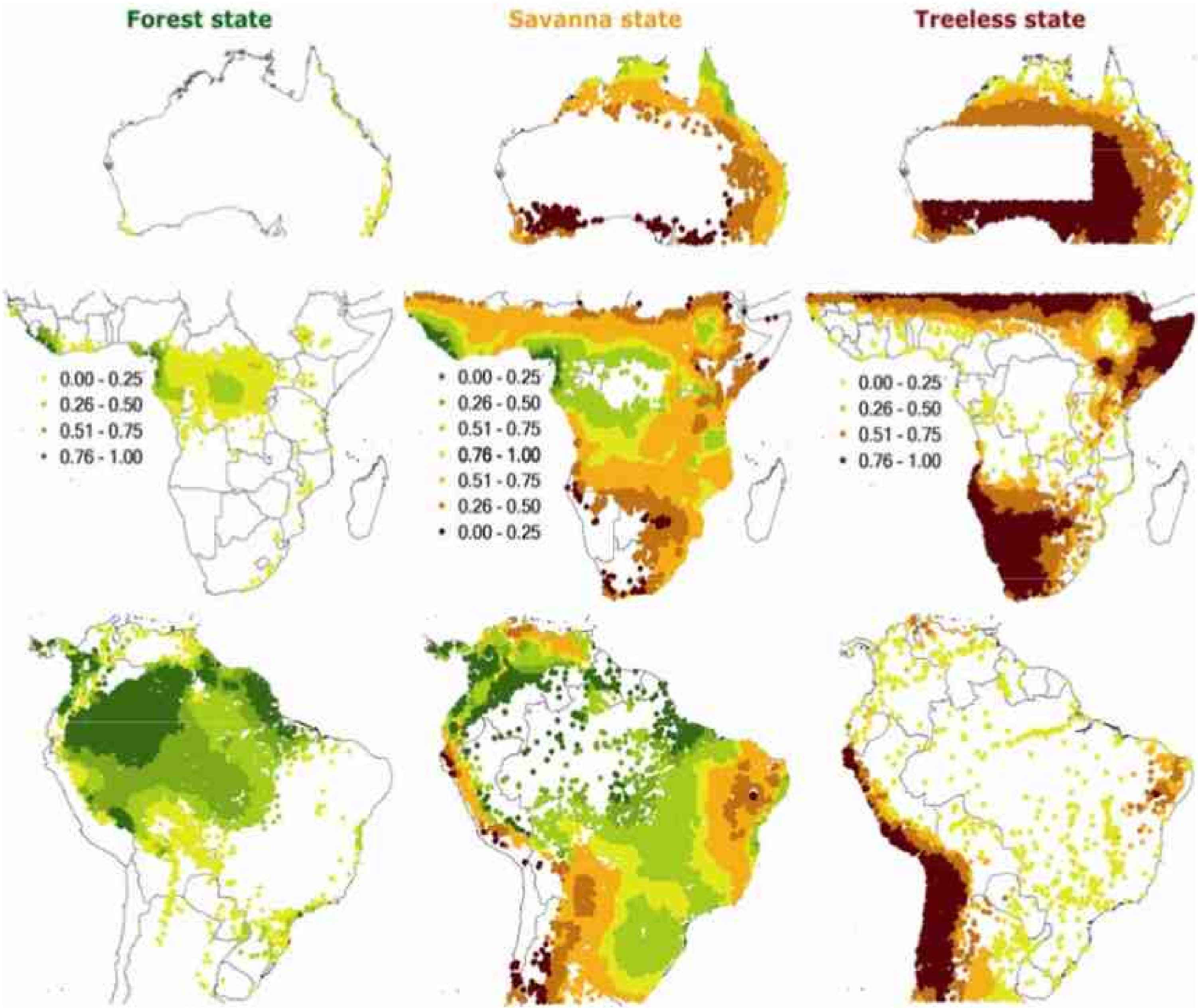


(Standish et al, in prep)

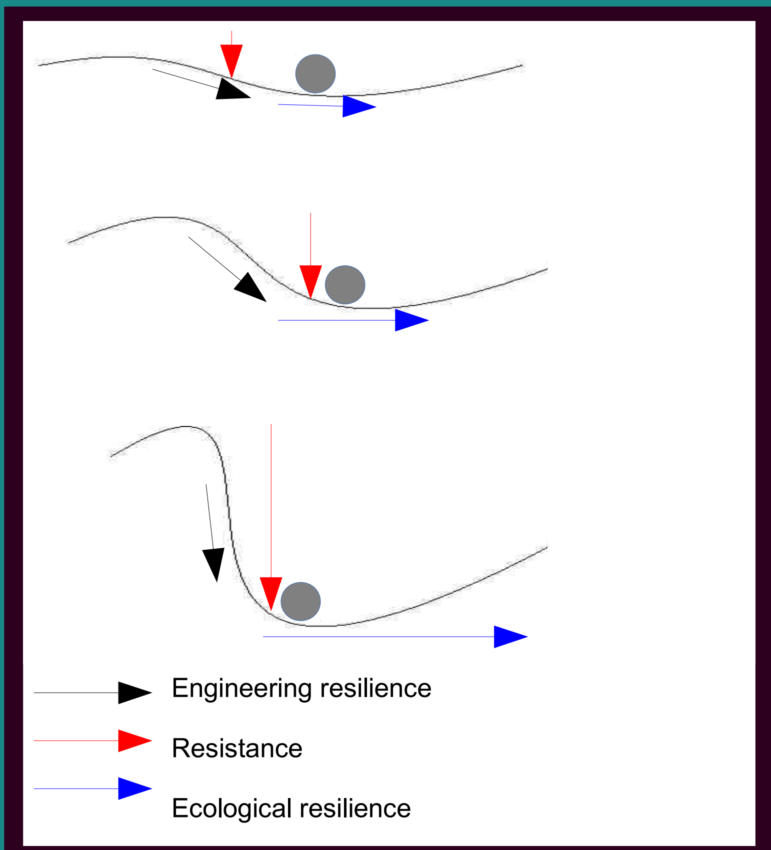


The Ol' Ball and Cup





Forest state
Savanna state
Treeless state
0.00 - 0.25
0.26 - 0.50
0.51 - 0.75
0.76 - 1.00
0.00 - 0.25
0.26 - 0.50
0.51 - 0.75
0.76 - 1.00
0.51 - 0.75
0.26 - 0.50
0.00 - 0.25
0.00 - 0.25
0.26 - 0.50
0.51 - 0.75
0.76 - 1.00



VOL. 169, NO. 6 THE AMERICAN NATURALIST JUNE 2007

Slow Recovery from Perturbations as a Generic Indicator of a Nearby Catastrophic Shift

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Submitted April 25, 2006; Accepted January 2, 2007; Electronically published April 17, 2007

Online enhancement: appendix.

ABSTRACT: The size of the basin of attraction in ecosystems with alternative stable states is often referred to as "ecological resilience." Ecosystems with a low ecological resilience may easily be tipped into an alternative basin of attraction by a stochastic event. Unfortunately,

tems (Brock and Durlauf 1999; Gladwell 2000; Adler 2001; Scheffer et al. 2003). It is difficult to prove experimentally that a system has multiple stable states (Scheffer and Carpenter 2003; Schröder et al. 2005), but the implications are profound if this phenomenon occurs in a system. A major problem from a management point of view is that slowly changing conditions can make such systems increasingly vulnerable to collapse into an alternative state. This typically happens in an invisible way, that is, without apparent effects on the state of the system. Such loss of resilience arises if the basin of attraction around the present state shrinks, making it increasingly likely that some stochastic event will tip the system into an alternative basin of attraction (fig. 1*a*, 1*b*). As an intuitive example, consider

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PLoS BIOLOGY

Perspective

Rethinking Ecosystem Resilience in the Face of Climate Change

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Resilience is usually defined as the capacity of an ecosystem to absorb disturbance without shifting to an alternative state and losing function and services [1–3]. The concept therefore encompasses two separate processes: resistance—the magnitude of disturbance that causes a change in structure—and recovery—the speed of return to the original structure [4,5]—which are fundamentally different but rarely distinguished. Yet, resilience has become a central concept in the management of natural ecosystems [6,7]. Many current management actions aim to alleviate local stressors in an effort to increase ecosystem resilience to global climate change [8,9]. Such a management philosophy is premised on the belief that eliminating local drivers of ecological change will increase the ability of an ecosystem to resist future climate disturbances, its ability to recover from such disturbances, or both [2,6]. Measuring resilience is fraught with difficulties [1,3]. Nevertheless, assessing changes in resilience as a result of management action is critical because there is general agreement for the existence of a strong link between resilience and sustainability [10]. Successfully increasing the resilience of natural systems may therefore have important implications for human welfare in the face of global climate change.

In this Perspective, we will argue that the expectation of increased resilience of natural communities to climate change through the reduction of local stressors may be fundamentally incorrect, and that resilience-focused management may, in fact, result in greater vulnerability to climate impacts. We illustrate our argument using coral reefs as a model. Coral reefs are in an ecological crisis due to climate change and the ever-increasing magnitude of human impacts on these biodiverse habitats [11,12]. These impacts stem from a multiplicity of local stressors, such as fishing, eutrophication, and sedimentation. It is therefore not surprising that the concept of resilience—to climate change in particular—is perhaps more strongly advocated as an underpinning of management for coral reefs than for any other ecosystem [9,11–16]. Marine reserves or no-take areas, the most popular form of spatial management for coral reef conservation, are widely thought to have the potential to increase coral reef resilience [11,13,14,17]. But do they really?

The Conventional View of Resilience

The concept of managing for resilience is underpinned by the notion that unstressed coral communities are highly resilient to climate change and that human-induced degradation erodes the ability of coral reefs to resist the impacts of climate disturbance, tipping degraded reefs into alternative, less desirable states sooner than pristine ones [13]. This conventional view is illustrated in the simple conceptual model shown in Figure 1, which depicts the potential relationships between ecosystem state and the strength of climate disturbance. Here, we focus on corals—the three-dimensional reef builders that are the foundation species for most reef communities [18]—thus ecosystem state could be measured as coral cover or coral species diversity, whereas climate disturbance can incorporate both a change in mean temperature or increased variability [19].

The model implies that more pristine coral communities will cross a tipping point and subsequently shift into an alternative ecosystem state—usually dominated by fleshy macroalgae [13] but other alternative states are possible [20]—only at high levels of climate disturbance (Figure 1A). As non-climatic, local disturbances degrade the original ecosystem (Figure 1A; open block arrows), the tipping point in response to climate change shifts to the left (Figure 1A; black arrows), making the ecosystem less resistant to climate disturbance. Management that seeks to control local stressors and reverse degradation (Figure 1A; red block arrows) is therefore expected to increase resilience by shifting the tipping point back to the right and keeping reefs further away from this ecological precipice (Figure 1A; red arrows).

If resilience to climate change varies in relation to ecosystem state as depicted in Figure 1A, then two general predictions arise. First, coral communities exposed to local or chronic disturbance should be more susceptible to climate change than less degraded communities. Second, corals in areas with management to control local disturbances should be less susceptible to climate perturbations than those in areas without similar management. We evaluate briefly the empirical evidence for each prediction below.

Are degraded communities more susceptible to climate change impacts?

Ecologists are increasingly aware that, in a variety of ecosystems, species loss following disturbance is non-random [3,21,22]. On coral reefs, selective mortality following disturbance has a direct impact of coral community structure, by changing the absolute and relative abundances of coral species [23]. Shifts in community assemblages have been ob-

The Perspective section provides experts with a forum to comment on topical or controversial issues of broad interest.

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Competing Interests: The authors have declared that no competing interests exist.

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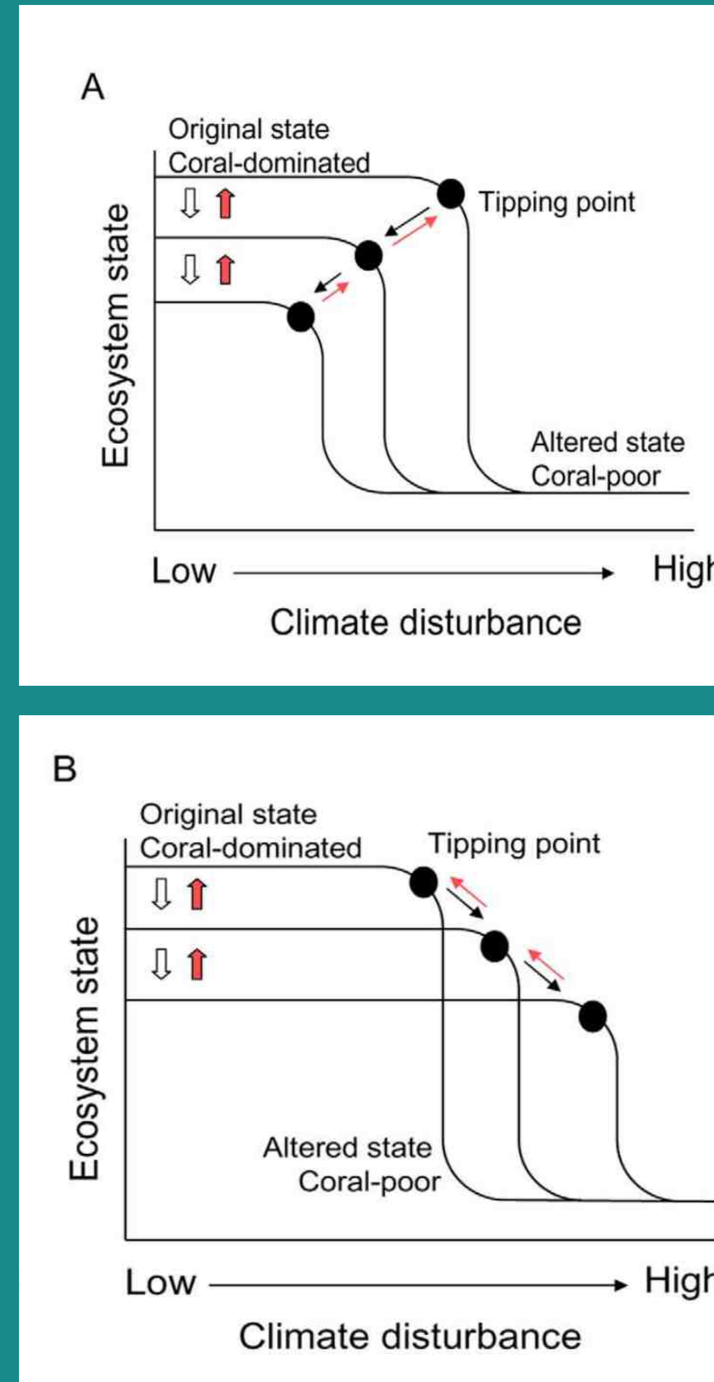
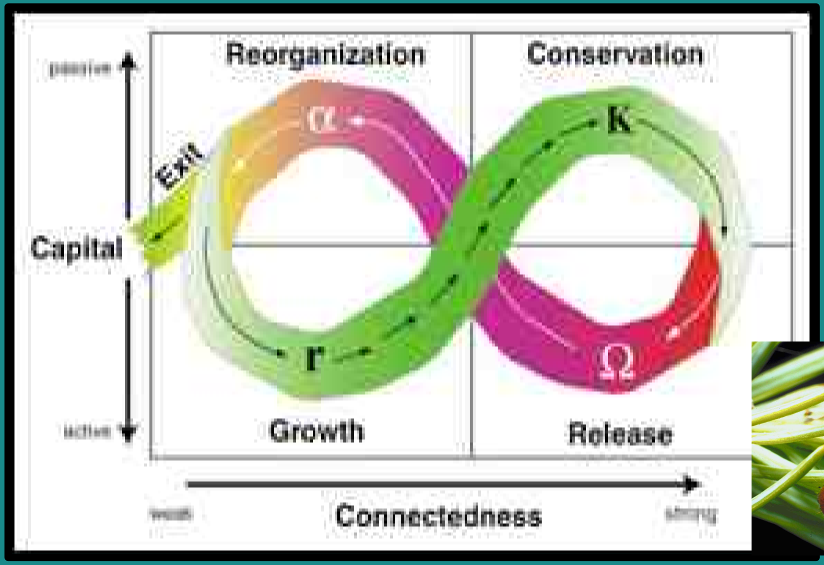
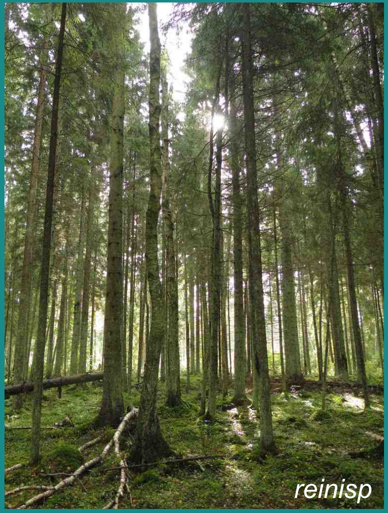


Socio-ecological systems: a system composed of organized assemblages of humans and non-human life forms in a spatially determined geophysical setting (Halliday and Glaser, 2011)

A: Balsam fir forest





B: Spruce/birch forest

Recap: Definitions

1) Ecological resilience – the magnitude of disturbance that can be absorbed before the system changes its structure by changing the variables and processes that control behavior (Gunderson and Holling, 2002)

2) Engineering resilience (recovery) – how fast the variables return towards their equilibrium following a perturbation (Pimm, 1984)

3) Resistance – the degree to which a variable is changed following a perturbation (Pimm, 1984)

Thomas P. Peschak

Ecosystem Resilience –

a 50 minute
(I promise that's quick)
summary

Nancy Shackelford, PhD Candidate
School of Environmental Studies

Some definitions

Grimm and Wissel. 1997: *Babel, or the ecological stability discussions: an inventory and analysis of terminology and a guide for avoiding confusion*

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
(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* – Zwölfer 78:15 Functional stability – Rejmánek 92:455 Perceived stability – Begon et al. 90:802 Persistence – Rahel 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 – Siljak 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 Species deletion stability – Pimm 80:142
(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 Responsivness – Roughgarden 75:6 Sensitivity – Estberg and Patten 76:152 Sensitivity* – Remmert 84:286 Vulnerability – Vincent and Anderson 79:218

Table 2 (continued)

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 Dynamical 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

Author	Definition	# Citations	Reference
1. Holling	A measure of the persistence of systems and of their ability to absorb change and disturbance and still maintain the same relationships between populations or state variables.	1743	Holling 1973
		294*	Holling 1996
2. Gunderson	Property of an ecosystem that describes the change in stability (or return time) and resilience (the width of the stability domain).	281	Gunderson 2000
3. Walker	Resilience (the capacity of a system to absorb disturbance and reorganize while undergoing change so as to still retain essentially the same function, structure, identity, and feed-backs). Resilience has four components—latitude, resist-ance, precariousness, and panarchy—most readily portrayed using the metaphor of a stability landscape.	269	Walker et al. 2004
4. Carpenter	The rate at which a system returns to equilibrium after dis-turbance.	90	Carpenter et al. 1992
	The magnitude of disturbance that can be tolerated before a socio-ecological system moves to a difference region of a state space controlled by a different set of processes, includ-ing the degree to which the system is capable of self-organization, and how much it expresses a capacity for learning and adaptation.	341	Carpenter et al. 2001
5. Pimm	How fast a variable that has been displaced from equilibrium returns to it. Resilience could be estimated by a return time: the amount of time taken for the displacement to decay to some specified fraction of its initial value.	1659*	Pimm 1991

Myers-Smith, *et al*. 2012. *Resilience: Easy to use but hard to define*

Ok, never mind. Let's start at the beginning

Professor C.S. (Buzz) Holling

RESILIENCE AND STABILITY OF ECOLOGICAL SYSTEMS ❖ 4050

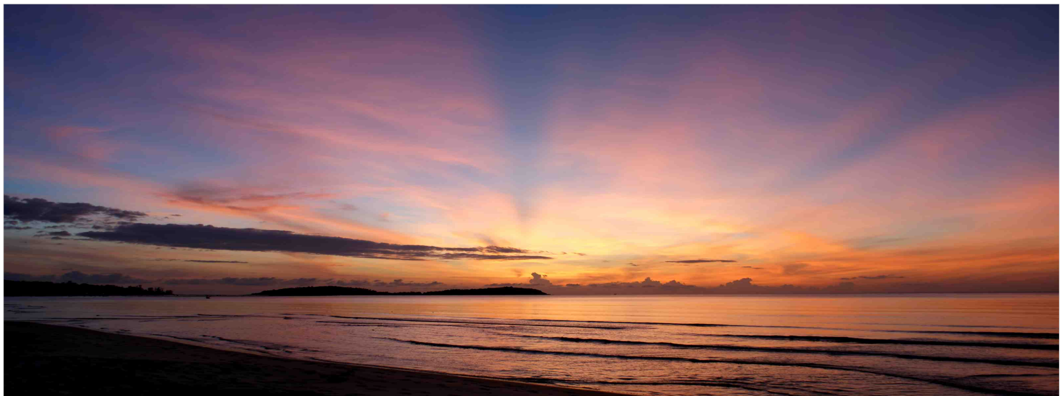
C. S. Holling
Institute of Resource Ecology, University of British Columbia, Vancouver, Canada

INTRODUCTION

Individuals die, populations disappear, and species become extinct. That is one view of the world. But another view of the world concentrates not so much on presence or absence as upon the numbers of organisms and the degree of constancy of their numbers. These are two very different ways of viewing the behavior of systems and the usefulness of the view depends very much on the properties of the system concerned. If we are examining a particular device designed by the engineer to perform specific tasks under a rather narrow range of predictable external conditions, we are likely to be more concerned with consistent nonvariable performance in which slight departures from the performance goal are immediately counteracted. A quantitative view of the behavior of the system is, therefore, essential. With attention focused upon achieving constancy, the critical events seem to be the amplitude and frequency of oscillations. But if we are dealing with a system profoundly affected by changes external to it, and continually confronted by the unexpected, the constancy of its behavior becomes less important than the persistence of the relationships. Attention shifts, therefore, to the qualitative and to questions of existence or not.

Our traditions of analysis in theoretical and empirical ecology have been largely inherited from developments in classical physics and its applied variants. Inevitably, there has been a tendency to emphasize the quantitative rather than the qualitative, for it is important in this tradition to know not just that a quantity is larger than another quantity, but precisely how much larger. It is similarly important, if a quantity fluctuates, to know its amplitude and period of fluctuation. But this orientation may simply reflect an analytic approach developed in one area because it was useful and then transferred to another where it may not be.

Our traditional view of natural systems, therefore, might well be less a meaningful reality than a perceptual convenience. There can in some years be more owls and fewer mice and in others, the reverse. Fish populations wax and wane as a natural condition, and insect populations can range over extremes that only logarithmic



'Ecological' resilience: “a measure of the persistence of systems and of their ability to absorb change and disturbance and still maintain the same relationships between populations or state variables”


NATIONAL GEOGRAPHIC
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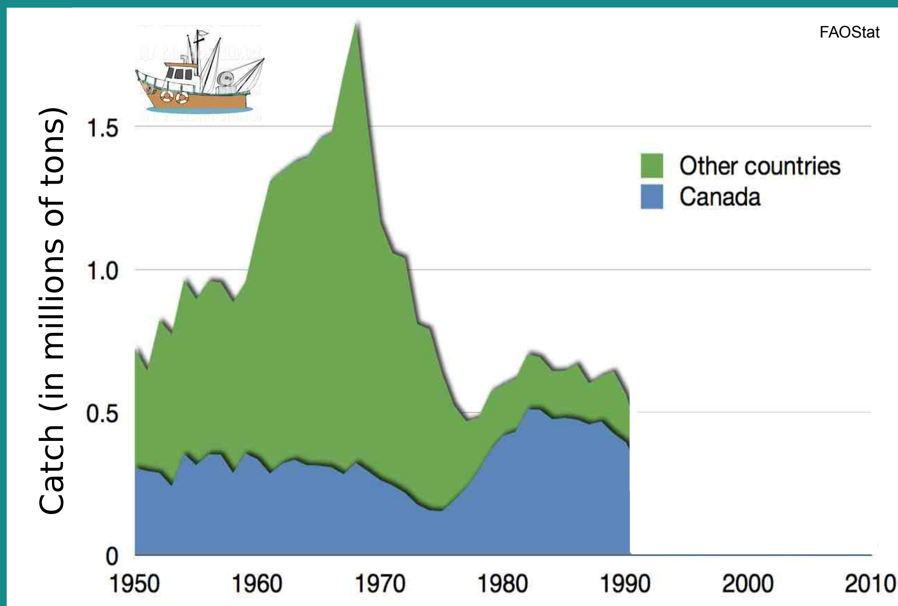
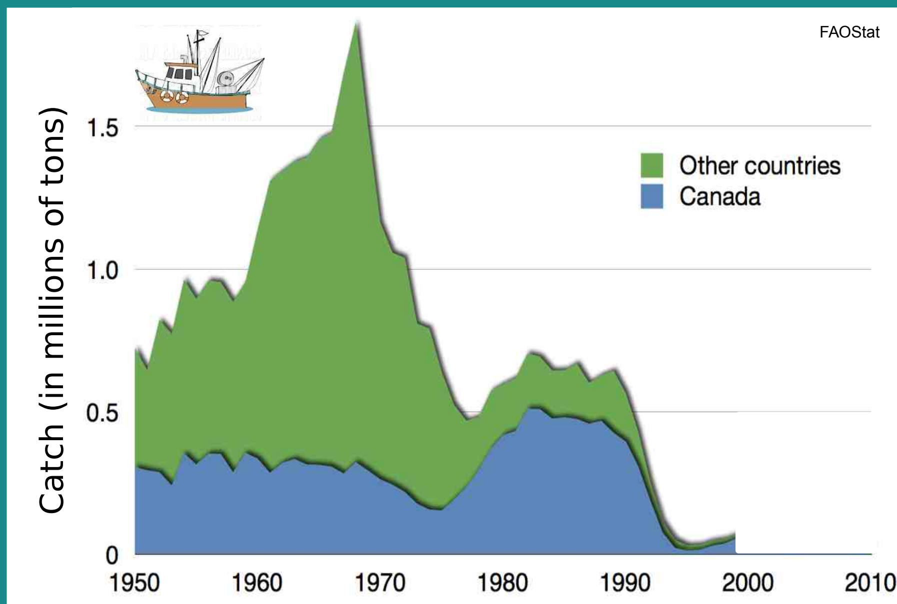


North Atlantic Cod collapse of 1992

These new technologies adversely affected the northern cod population in two important ways: by increasing the area and depth that was fished, the cod were being depleted until the surviving fish could not replenish the stock lost each year;[7] and secondly, the trawlers caught enormous amounts of non-commercial fish, which were economically unimportant but very important ecologically: incidental catch undermines the whole ecosystem, depleting stocks of important predator and prey species. With the northern cod, significant amounts of capelin – an important prey species for the cod – were caught as bycatch, further undermining the survival of the remaining cod stock.



North Atlantic Cod collapse of 1992

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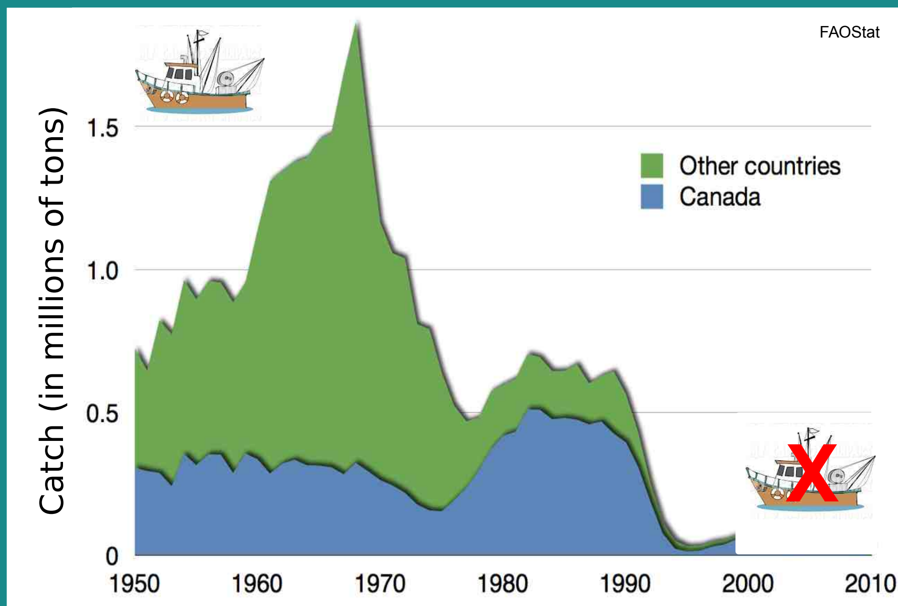
We suggest that lake trout historically may have controlled the lake’s fish community by suppressing potential competitors/predators and that fishing-induced biomass reductions compromised this function.

Archived records indicate that sea lampreys reached pest levels of abundance by 1946. In northern Michigan waters, catches per unit of effort (CPUEs) of adult lake trout aggregated on six spawning reefs declined between 1942 and 1943. Furthermore, poor recr uitment of juvenile lake trout from these same waters, evident in 1949, indicated that lake trout reproduction was impaired as early as 1944



North Atlantic Cod collapse of 1992

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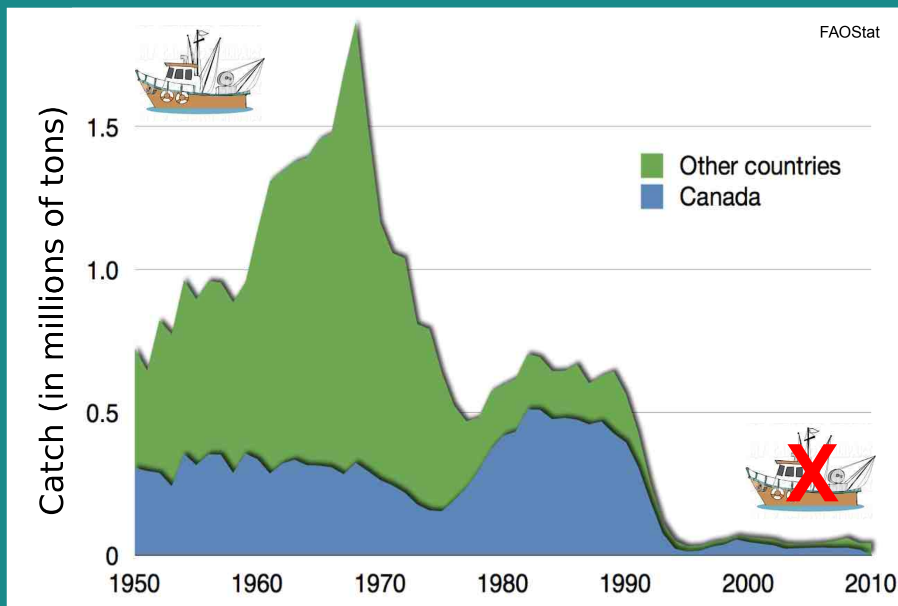

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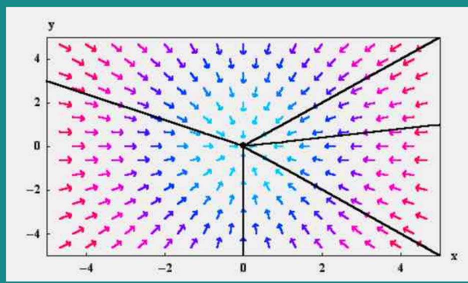
Brocken Inaglory
Linda Pitkin

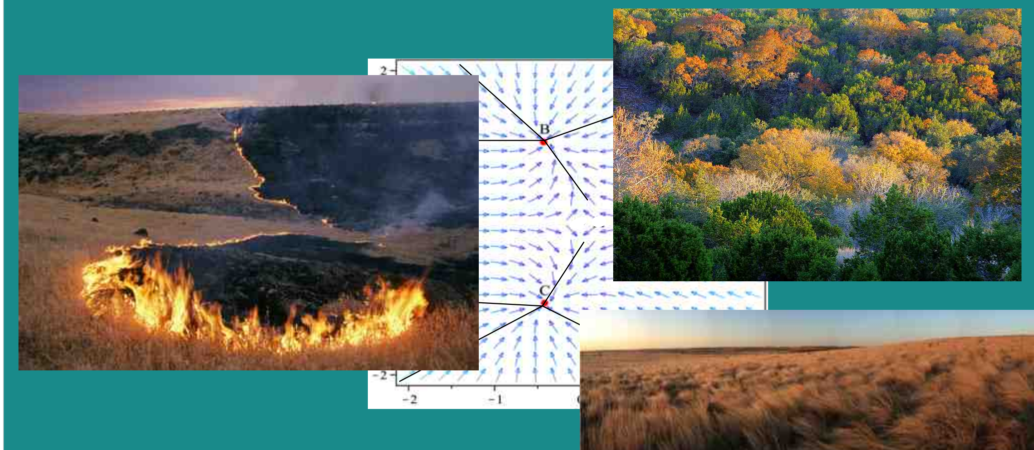
Revolution!

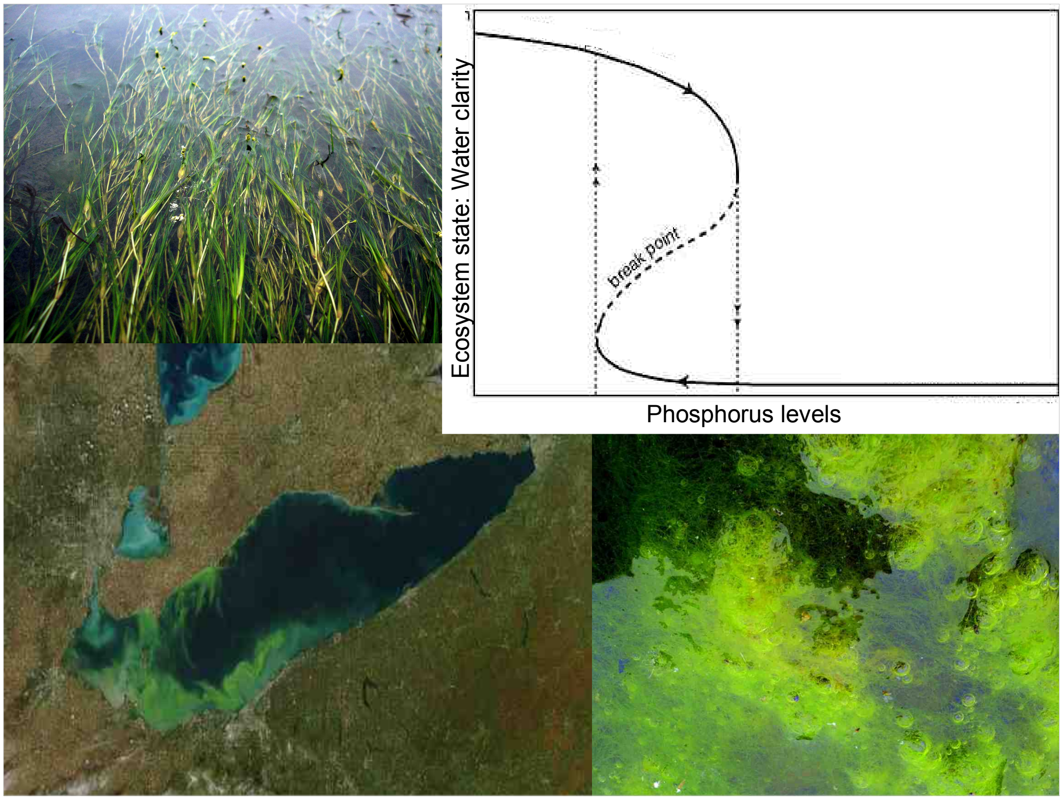
The idea that there is a 'balance of nature' is commonly held by biologists. They feel that the organisms in a community are harmoniously adjusted to one another so that a state of dynamic equilibrium exists. In this equilibrium the numbers of individuals of each species in the community remain relatively constant and significant changes in numbers occur only when something upsets the natural “balance”. (Ehrlich and Birch, 1967)



Alternative stable states

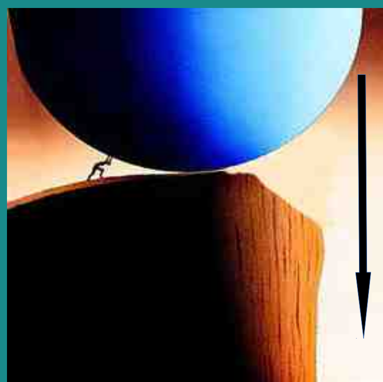
The theory that ecological systems may exist potentially indefinitely in contrasting states under the same external environmental conditions

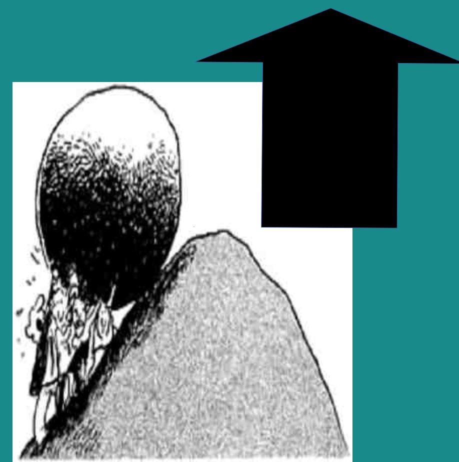


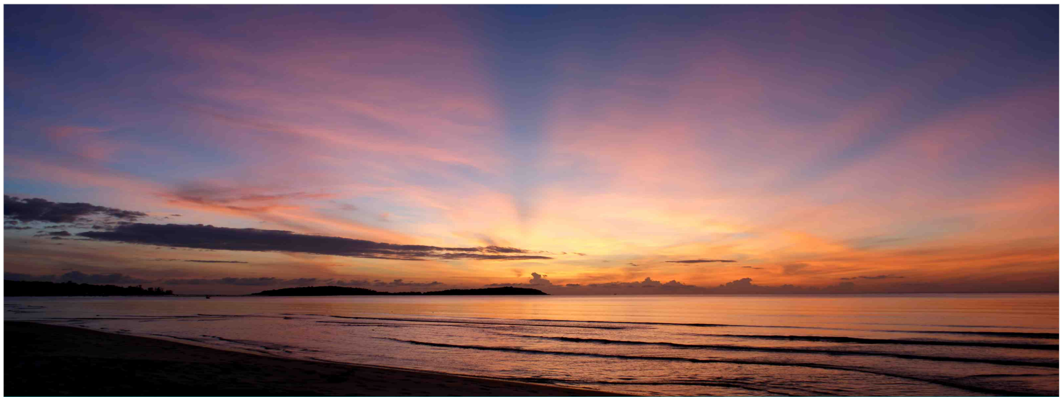


Once P enters the lake, it may be taken up by primary producers (including the undesirable blue-green algae that are symptomatic of eutrophication) or added to the sediments. P
in the lake cycles continually among organisms, the water, and the sediment. Recycling from sediment to the overlaying water is a key flux that is subject to nonlinear changes in rate. When P levels in the water are low, oxygen concentrations stay high throughout the summer and P remains bound in iron complexes in the sediment. When P levels in the water are high, the production of algae is high and decomposition of sinking algae depletes oxygen near the surface of the sediment. The iron complexes are chemically reduced, releasing the P in soluble form to support further algal growth. This
shift between negative and positive feedbacks produces alternate stable states one with low water P, low recycling, and high water quality; the other with high water P, high recycling, and poor water quality

Hysteresis





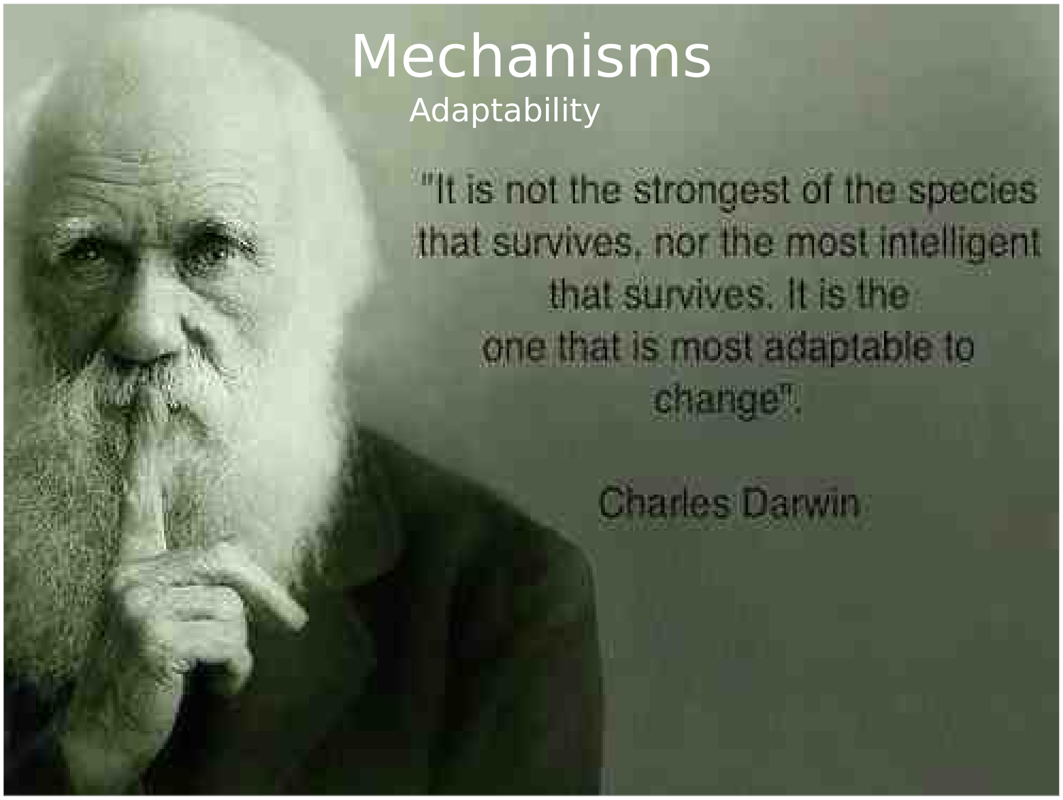


'Ecological' resilience – which ecosystems are more resilient? Which are less? How do we predict?

Mechanisms

Ecosystem and disturbance-
specific mechanisms

(..resilience *of* what *to* what?)


Mechanisms
Adaptability
"It is not the strongest of the species
that survives, nor the most intelligent
that survives. It is the
one that is most adaptable to
change".
Charles Darwin

Vol. 121, No. 6 The American Naturalist June 1983

ON THE EVIDENCE NEEDED TO JUDGE ECOLOGICAL STABILITY OR PERSISTENCE

Joseph H. Connell* and Wayne P. Sousa

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Submitted September 17, 1981; Revised October 14, 1982; Accepted November 4, 1982

"The balance of nature has been a background assumption in natural history since antiquity" (Egerton 1973, p. 322). This continues to be true today; some modern field ecologists, assuming that natural ecosystems are stable, have applied ideas of mathematical stability theory to the actual communities they are studying. We believe that, before one applies such theory to a natural population or community, one should first decide whether or not it is stable. Our aim here is to describe the sorts of evidence one would need to obtain from natural populations or communities in order to decide whether they are stable or persistent, as defined below. One aspect we shall stress in particular is whether any given real community exists in multiple stable states in different places at the same time or in the same place at different times (Sutherland 1974).

When considering changes in natural populations and communities, it is important to distinguish between two viewpoints. As Holling (1973) has pointed out, one view is concerned with the degree of constancy in the numbers of organisms. With this view, stability is the property of interest. In contrast is the view that concentrates, not on constancy of numbers, but on presence or absence. He states (1973, p. 1): "If we are dealing with a system profoundly affected by changes external to it, and continually confronted by the unexpected, the constancy of its behavior becomes less important than the persistence of the relationships. Attention shifts, therefore, to the qualitative and to questions of existence or not."

Past discussions of stability have sometimes confused these two viewpoints and have also applied identical terms to both. Therefore we would like first to define and discuss the terms we will use in this paper, as well as those previously used. Some of these terms have also been applied by theoretical and mathematical workers to model ecosystems under particular specified assumptions. We want to emphasize that our usage applies not to these models but only to the real world. We are not interested in testing the assumptions of these models, nor in using them to interpret data from actual ecosystems. We do not seek to contribute here

* Order of authorship decided by flip of a coin.
Address reprint requests to W. Sousa.

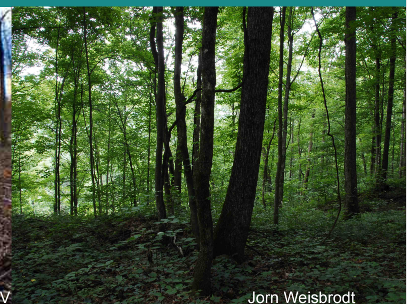
Am. Nat. 1983. Vol. 121, pp. 789–824.

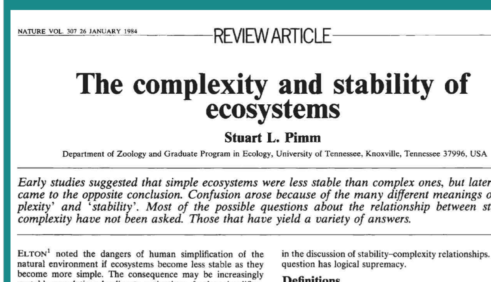
1. Remains at state when disturbed or returns after disturbance

2. Remains at state either for one full generation time for all organisms OR a time length such that replacement of all organisms has ocurred (as juveniles)

3. Exists under same physical conditions as alternative state

Recovery





NATURE VOL. 307 26 JANUARY 1984 — REVIEW ARTICLE

The complexity and stability of ecosystems

Stuart L. Pimm

Department of Zoology and Graduate Program in Ecology, University of Tennessee, Knoxville, Tennessee 37996, USA

Early studies suggested that simple ecosystems were less stable than complex ones, but later came to the opposite conclusion. Confusion arose because of the many different meanings o plexity' and 'stability'. Most of the possible questions about the relationship between st complexity have not been asked. Those that have yield a variety of answers.

ELTON[1] noted the dangers of human simplification of the natural environment if ecosystems become less stable as they become more simple. The consequence may be increasingly unstable populations leading to extinctions, further simplifica-

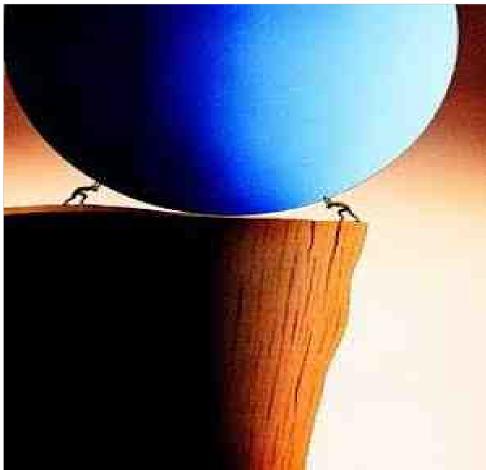
in the discussion of stability–complexity relationships. question has logical supremacy.

Definitions

'Engineering resilience': “How fast the variables return towards their equilibrium following a perturbation. Resilience is not, therefore, defined for unstable systems.


Mechanisms
Functional redundancy

Mechanisms
Landscape context



Resistance

the degree to which a variable is changed following a perturbation


Mechanisms
Response diversity
Copyright © Abrie Niemann Photography
PARAMEDIC

Mechanisms

Spatial configuration

Press Pulse


Biodiversity


Landscape context
Gerry Ellis

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

ECOSYSTEMS
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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 Abel[2]

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

Abstract

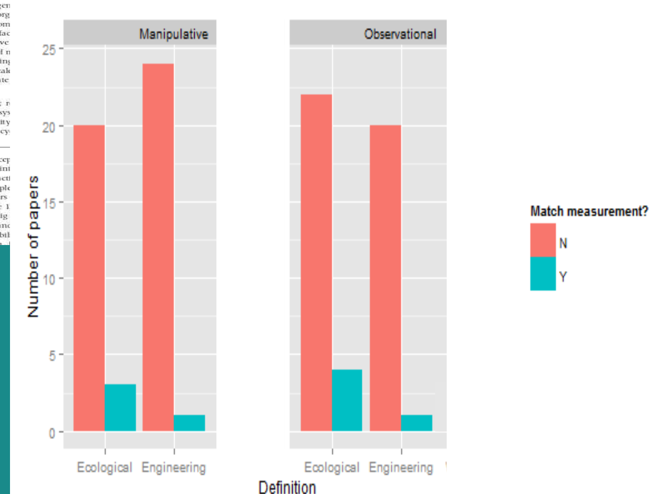
Resilience is the magnitude of disturbance that can be tolerated before a socioecological system (SES) moves to a different region of state space controlled by a different set of processes. Resilience has multiple levels of meaning: as a metaphor related to sustainability, as a property of dynamic models, and as a measurable quantity that can be assessed in field studies of SES. The operational indicators of resilience have, however, received little attention in the literature. To assess a system's resilience, one must specify which system configuration and which disturbances are of interest. This paper compares resilience properties in two contrasting SES, lake districts and rangelands, with respect to the following three general features: (a) The ability of an SES to stay in the domain of attraction is related to slowly changing variables, or slowly changing disturbance regimes, which control the boundaries of the domain of attraction or the frequency of events that could push the system across the boundaries. Examples are soil phosphorus content in lake districts woody vegetation cover in rangelands, and property rights systems that affect land use in both lake districts and rangelands. (b) The ability of an
SES to self-organize is rela
reorganization is endogen
external drivers. Self-org
coevolved ecosystem com
of social networks that fac
solving. (c) The adaptive
lated to the existence of n
tion of novelty or learning
versity at multiple scal
institutions that facilitate
ery, and innovation.

Key words: resilience; r
tence; socioecological sys
rangelands; sustainability
tive capacity; adaptive cy

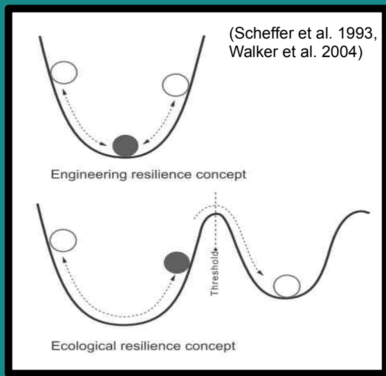
Introduction

In the rapidly developing area of research on ecosystem services and the people who depend on them, the term "resilience" is often used to describe the characteristic features of a system that are related to sustainability. As a technical term, the idea of "resilience" originated in the field of ecology (Holling 1973). Diverse definitions of resilience and other concepts related to stability can be found in

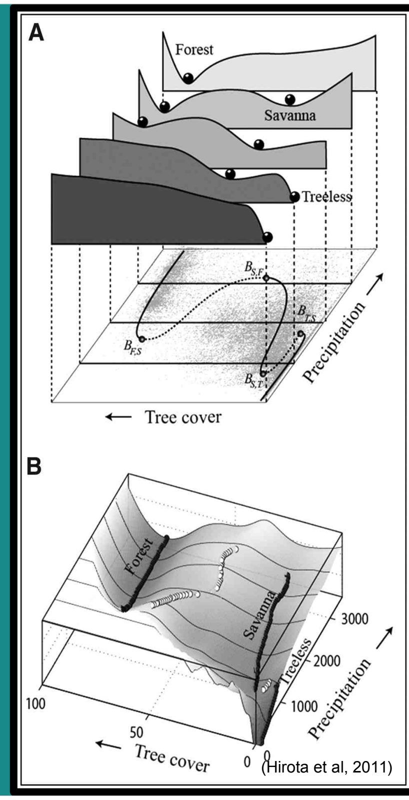
McCoy 1993). The concep
in a great variety of in
cerned with the interact
nature (see, for exampl
1995; Hanna and others
1997; Berkes and Folke 1
and Nichols 1999; Kinzig
son 2000; Gunderson and
silience" and "sustainabi

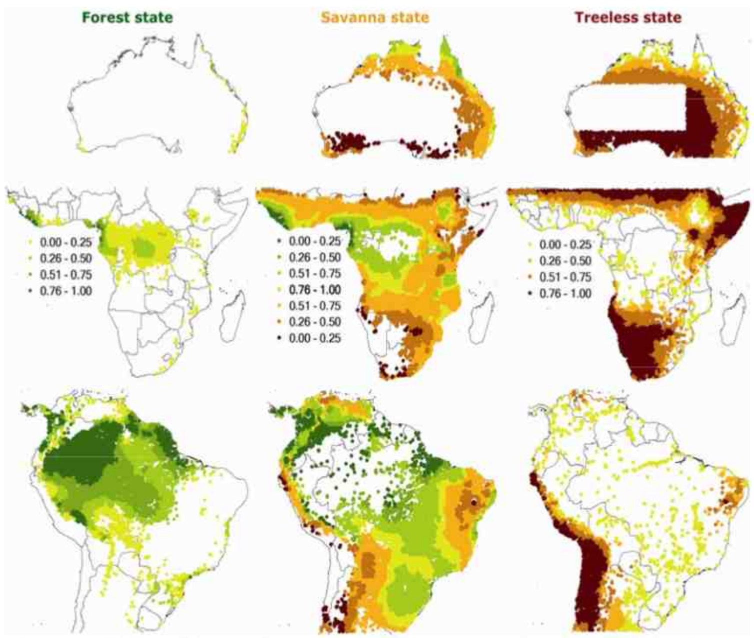


(Standish et al, in prep)

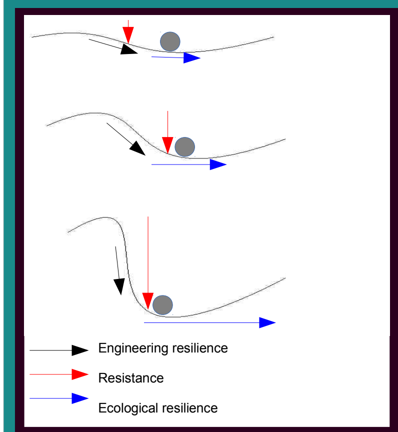


The Ol' Ball and Cup





Forest state
Savanna state
Treeless state
0.00 - 0.25
0.26 - 0.50
0.51 - 0.75
0.76 - 1.00
0.00 - 0.25
0.26 - 0.50
0.51 - 0.75
0.76 - 1.00
0.51 - 0.75
0.26 - 0.50
0.00 - 0.25
0.00 - 0.25
0.26 - 0.50
0.51 - 0.75
0.76 - 1.00



VOL. 169, NO. 6 THE AMERICAN NATURALIST JUNE 2007

Slow Recovery from Perturbations as a Generic Indicator of a Nearby Catastrophic Shift

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Submitted April 25, 2006; Accepted January 2, 2007; Electronically published April 17, 2007

Online enhancement: appendix.

ABSTRACT: The size of the basin of attraction in ecosystems with alternative stable states is often referred to as "ecological resilience." Ecosystems with a low ecological resilience may easily be tipped into an alternative basin of attraction by a stochastic event. Unfortunately,

tems (Brock and Durlauf 1999; Gladwell 2000; Adler 2001; Scheffer et al. 2003). It is difficult to prove experimentally that a system has multiple stable states (Scheffer and Carpenter 2003; Schröder et al. 2005), but the implications are profound if this phenomenon occurs in a system. A major problem from a management point of view is that slowly changing conditions can make such systems increasingly vulnerable to collapse into an alternative state. This typically happens in an invisible way, that is, without apparent effects on the state of the system. Such loss of resilience arises if the basin of attraction around the present state shrinks, making it increasingly likely that some stochastic event will tip the system into an alternative basin of attraction (fig. 1*a*, 1*b*). As an intuitive example, consider

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PLoS BIOLOGY

Perspective

Rethinking Ecosystem Resilience in the Face of Climate Change

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Resilience is usually defined as the capacity of an ecosystem to absorb disturbance without shifting to an alternative state and losing function and services [1–3]. The concept therefore encompasses two separate processes: resistance—the magnitude of disturbance that causes a change in structure—and recovery—the speed of return to the original structure [4,5]—which are fundamentally different but rarely distinguished. Yet, resilience has become a central concept in the management of natural ecosystems [6,7]. Many current management actions aim to alleviate local stressors in an effort to increase ecosystem resilience to global climate change [8,9]. Such a management philosophy is premised on the belief that eliminating local drivers of ecological change will increase the ability of an ecosystem to resist future climate disturbances, its ability to recover from such disturbances, or both [2,6]. Measuring resilience is fraught with difficulties [1,3]. Nevertheless, assessing changes in resilience as a result of management action is critical because there is general agreement for the existence of a strong link between resilience and sustainability [10]. Successfully increasing the resilience of natural systems may therefore have important implications for human welfare in the face of global climate change.

In this Perspective, we will argue that the expectation of increased resilience of natural communities to climate change through the reduction of local stressors may be fundamentally incorrect, and that resilience-focused management may, in fact, result in greater vulnerability to climate impacts. We illustrate our argument using coral reefs as a model. Coral reefs are in an ecological crisis due to climate change and the ever-increasing magnitude of human impacts on these biodiverse habitats [11,12]. These impacts stem from a multiplicity of local stressors, such as fishing, eutrophication, and sedimentation. It is therefore not surprising that the concept of resilience—to climate change in particular—is perhaps more strongly advocated as an underpinning of management for coral reefs than for any other ecosystem [9,11–16]. Marine reserves or no-take areas, the most popular form of spatial management for coral reef conservation, are widely thought to have the potential to increase coral reef resilience [11,13,14,17]. But do they really?

The Conventional View of Resilience

The concept of managing for resilience is underpinned by the notion that unstressed coral communities are highly resilient to climate change and that human-induced degradation erodes the ability of coral reefs to resist the impacts of climate disturbance, tipping degraded reefs into alternative, less desirable states sooner than pristine ones [13]. This conventional view is illustrated in the simple conceptual model shown in Figure 1, which depicts the potential relationships between ecosystem state and the strength of climate disturbance. Here, we focus on corals—the three-dimensional reef builders that are the foundation species for most reef communities [18]—thus ecosystem state could be measured as coral cover or coral species diversity, whereas climate disturbance can incorporate both a change in mean temperature or increased variability [19].

The model implies that more pristine coral communities will cross a tipping point and subsequently shift into an alternative ecosystem state—usually dominated by fleshy macroalgae [13] but other alternative states are possible [20]—only at high levels of climate disturbance (Figure 1A). As non-climatic, local disturbances degrade the original ecosystem (Figure 1A; open block arrows), the tipping point in response to climate change shifts to the left (Figure 1A; black arrows), making the ecosystem less resistant to climate disturbance. Management that seeks to control local stressors and reverse degradation (Figure 1A; red block arrows) is therefore expected to increase resilience by shifting the tipping point back to the right and keeping reefs further away from this ecological precipice (Figure 1A; red arrows).

If resilience to climate change varies in relation to ecosystem state as depicted in Figure 1A, then two general predictions arise. First, coral communities exposed to local or chronic disturbance should be more susceptible to climate change than less degraded communities. Second, corals in areas with management to control local disturbances should be less susceptible to climate perturbations than those in areas without similar management. We evaluate briefly the empirical evidence for each prediction below.

Are degraded communities more susceptible to climate change impacts?

Ecologists are increasingly aware that, in a variety of ecosystems, species loss following disturbance is non-random [3,21,22]. On coral reefs, selective mortality following disturbance has a direct impact of coral community structure, by changing the absolute and relative abundances of coral species [23]. Shifts in community assemblages have been ob-

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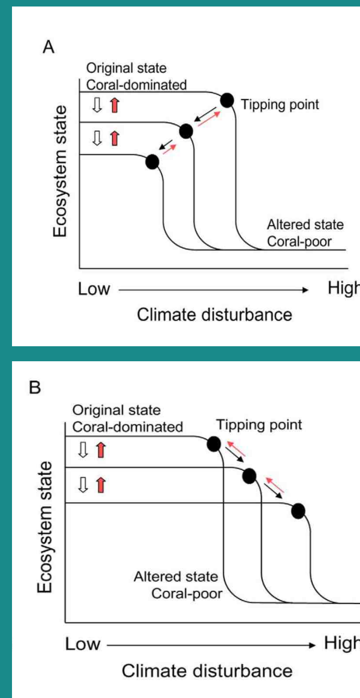
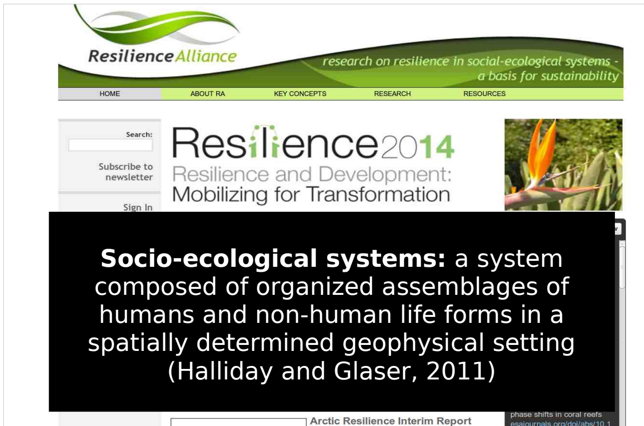
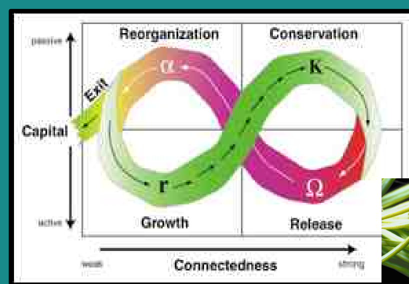




Socio-ecological systems: a system composed of organized assemblages of humans and non-human life forms in a spatially determined geophysical setting (Halliday and Glaser, 2011)

A: Balsam fir forest



B: Spruce/birch forest

Recap: Definitions

1) Ecological resilience – the magnitude of disturbance that can be absorbed before the system changes its structure by changing the variables and processes that control behavior (Gunderson and Holling, 2002)

2) Engineering resilience (recovery) – how fast the variables return towards their equilibrium following a perturbation (Pimm, 1984)

3) Resistance – the degree to which a variable is changed following a perturbation (Pimm, 1984)


Questions?
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