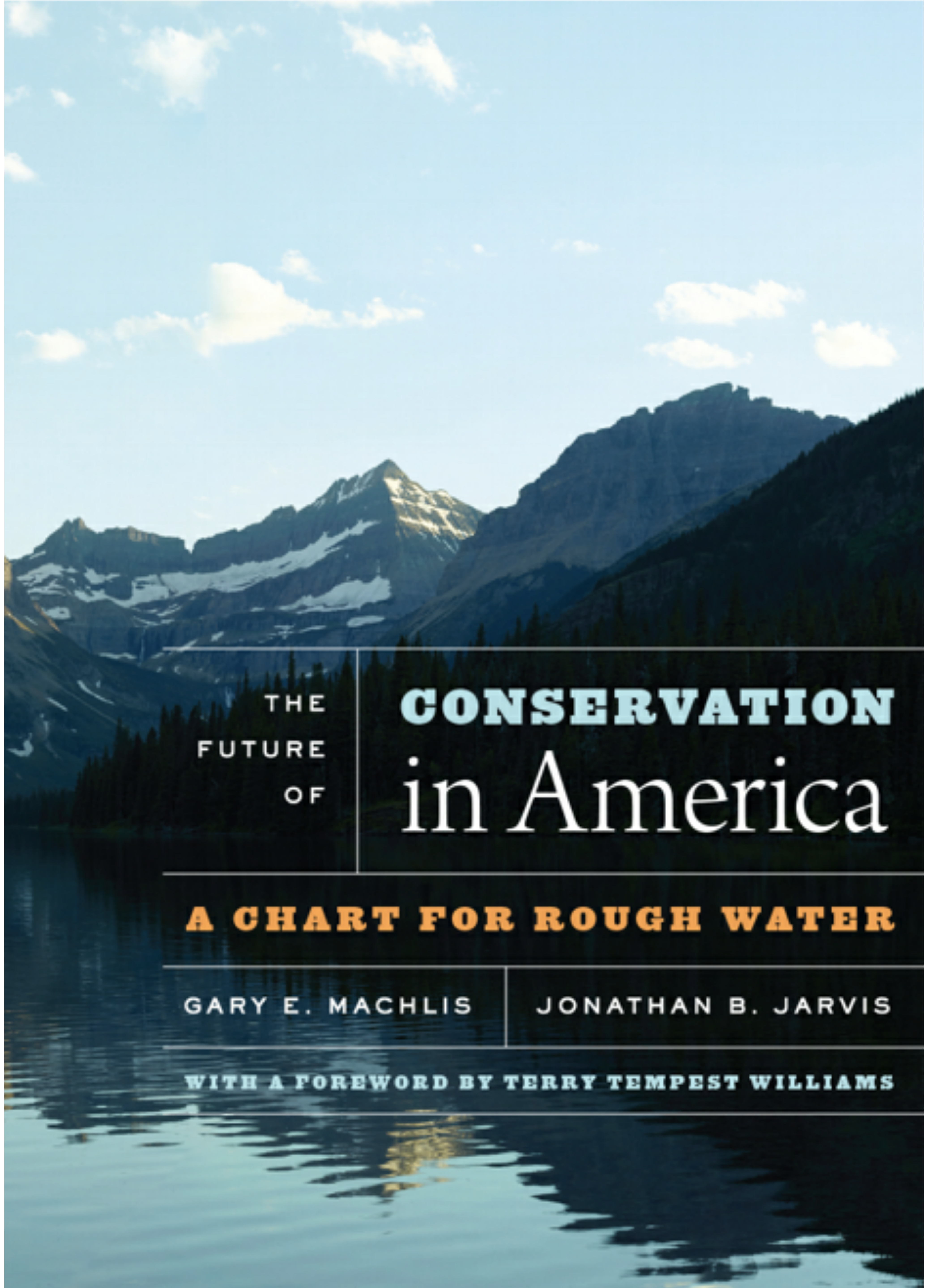
THE FUTURE OF
CONSERVATION in America
A CHART FOR ROUGH WATER
GARY E. MACHLIS
JONATHAN B. JARVIS
WITH A FOREWORD BY TERRY TEMPEST WILLIAMS

Mitigation and Adaptation Studies

Mitigation and Adaptation Studies

Class 16 (continued):

Vulnerabilities of Natural and Human Built Environment; Economy, Inequality and Injustice

Contents

- Terminology: What are risk, vulnerability, resilience, adaptation?
- Vulnerabilities of the natural and built environment to climate change and sea level rise
- Inequality and Injustice in Climate and Global Change Impacts
- Economic Risks

Terminology

Risk

Terminology

Risk

Insurance:

Risk (in $) = Hazard Probability * Vulnerability * Exposed Assets

Terminology

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Risk = Event rate * vulnerability * consequences

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Inability of a system to withstand the effects of a hostile environment.

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Inability of a system to withstand the effects of a hostile environment.

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The extent to which a community could be affected by stress, change or a hazard.

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Risk = Event rate * vulnerability * consequences

Vulnerability:
Inability of a system to withstand the effects of a hostile environment.

Social vulnerability:
The extent to which a community could be affected by stress, change or a hazard.

Here we take a risk-based approach that is commonly used for natural hazards and particularly geohazards. For a given hazard h, a given recurrence time interval T, and for a prescribed intensity I, the associated risk $r(I)$ expressed in currency is given by

$$r_h^T(I,x,t) = p_h^T(I,t) \cdot V_h^{a(x,t)}(I,t) \cdot a(x,t) \quad [1]$$

where x is the location, t time, p the hazard giving the probability that the hazard with intensity I will occur in the considered recurrence interval, V the vulnerability of an asset a for hazard h at intensity I, and a being the asset exposed at location x. To assess the total risk R associated with a hazard, we can use

$$R_h^T(x,t) = \int_0^{I_{\max}} r_h^T(I,x,t)\mathrm{d}i. \quad [2]$$

Risk (in $) = Hazard Probability * Vulnerability * Exposed Assets

$$r_h^T(I, x, t) = p_h^T(I, t) \cdot V_h^{a(x,t)}(I, t) \cdot a(x, t)$$

Terminology

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Application of equation suffers from:

- underestimation of probability, particularly for infrequent, large events
- worst cases are more frequent and worse than estimated

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Application of equation suffers from:

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- worst cases are more frequent and worse than estimated

- probability of extreme events is often underestimated:
- bad physics (incorrect description of processes)
- bad assumptions (choice of poorly known parameters)
- bad data (lacking, incomplete, or underappreciated)
- bad luck (low probability events) (Stein, 2011, 2012)

Terminology

Risk (in $) = Hazard Probability * Vulnerability * Exposed Assets

$$r_h^T(I, x, t) = p_h^T(I, t) \cdot V_h^{a(x,t)}(I, t) \cdot a(x, t)$$

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Risk defined as above:

- does not consider short-term induced and post-event processes
- does not consider cascading hazards
- does not consider cascading effects
- does not consider long-term post-event processes

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Risk defined as above:

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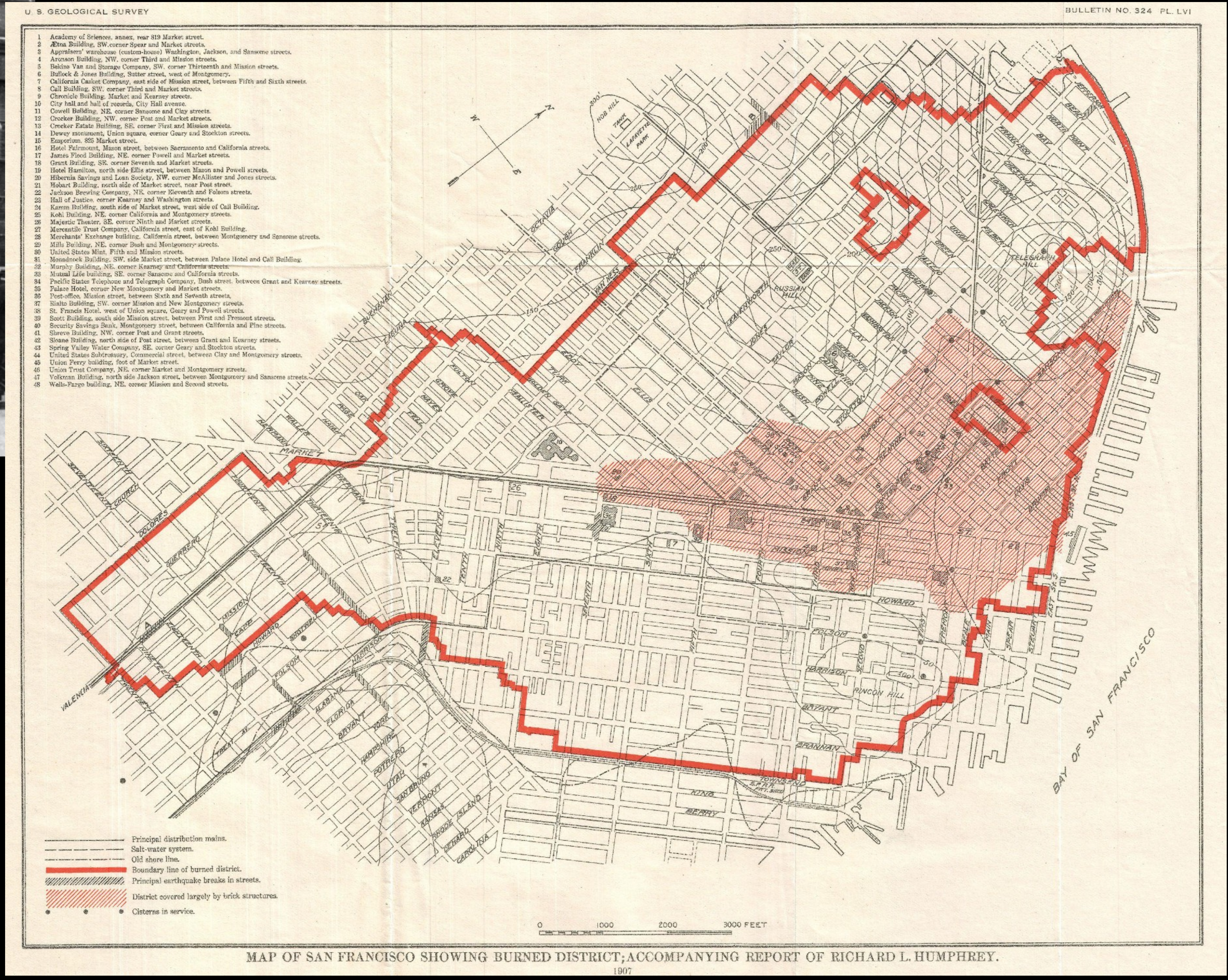
- does not consider cascading hazards
- does not consider cascading effects
- does not consider long-term post-event processes

- e.g., earthquakes trigger tsunamis, landslides, fires
- e.g., fires destroy health facilities

Example: 1906 San Francisco Earthquake



Example: 2011 Tohoku-Oki Earthquake

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Renesas Electronics, after the earthquake,
causing problems for the global auto industry

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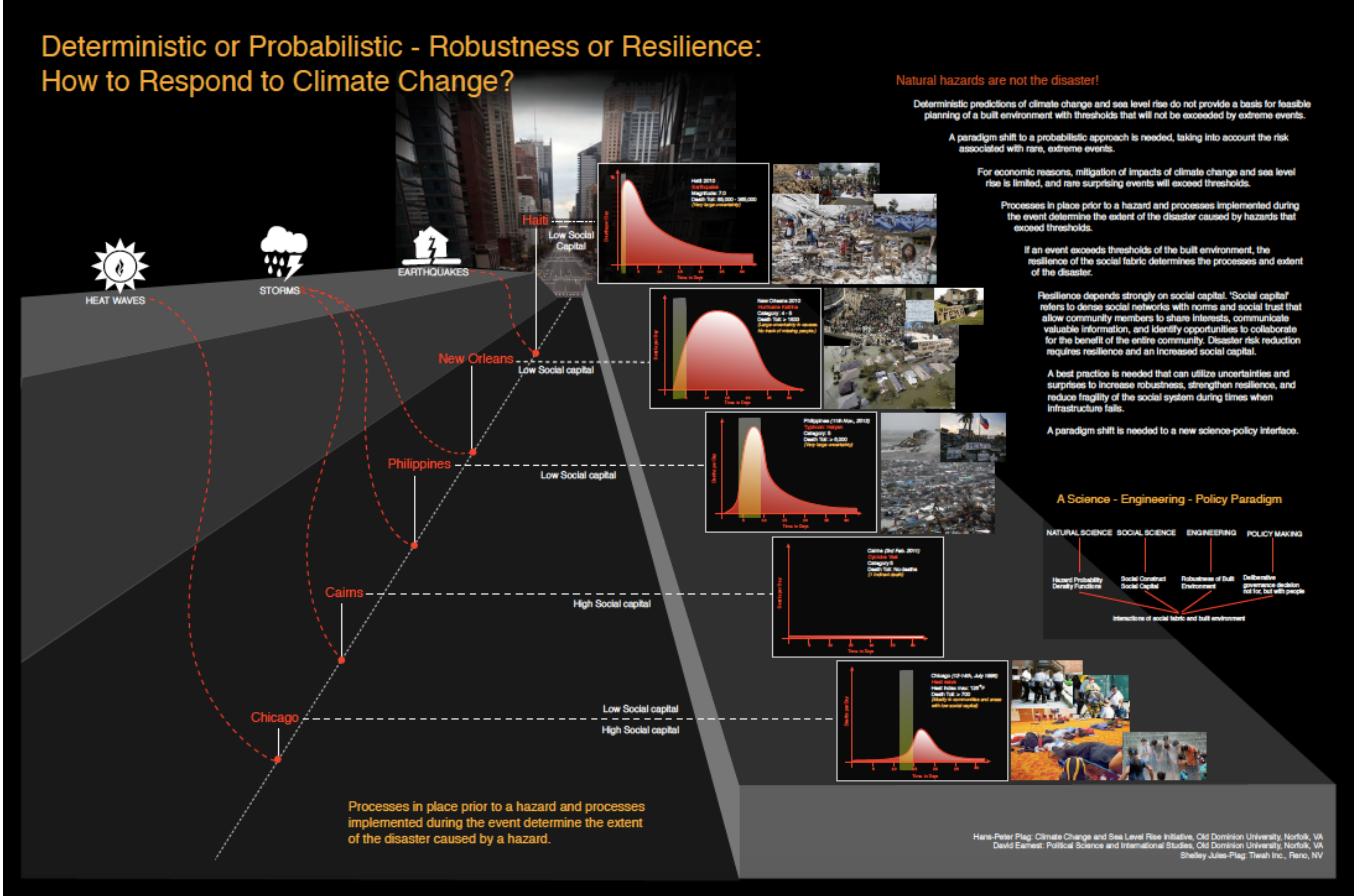
Renesas Electronics, after the earthquake, causing problems for the global auto industry

May 2012: All fifteen bluefin tunas tested in S. California were contaminated



Deterministic or Probabilistic - Robustness or Resilience:
How to Respond to Climate Change?
HEAT WAVES
STORMS
EARTHQUAKES
Haiti
Low Social Capital
New Orleans
Low Social capital
Philippines
Low Social capital
Cairns
High Social capital
Chicago
Low Social capital
High Social capital
Processes in place prior to a hazard and processes implemented during the event determine the extent of the disaster caused by a hazard.
Natural hazards are not the disaster!
Deterministic predictions of climate change and sea level rise do not provide a basis for feasible planning of a built environment with thresholds that will not be exceeded by extreme events.
A paradigm shift to a probabilistic approach is needed, taking into account the risk associated with rare, extreme events.
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Resilience depends strongly on social capital. 'Social capital' refers to dense social networks with norms and social trust that allow community members to share interests, communicate valuable information, and identify opportunities to collaborate for the benefit of the entire community. Disaster risk reduction requires resilience and an increased social capital.
A best practice is needed that can utilize uncertainties and surprises to increase robustness, strengthen resilience, and reduce fragility of the social system during times when infrastructure fails.
A paradigm shift is needed to a new science-policy interface.
A Science - Engineering - Policy Paradigm
NATURAL SCIENCE
SOCIAL SCIENCE
ENGINEERING
POLICY MAKING
Hazard Probability Density Functions
Social Construct Social Capital
Robustness of Built Environment
Deliberative governance decision not for, but with people
Interactions of social fabric and built environment
Hans-Peter Plag: Climate Change and Sea Level Rise Initiative, Old Dominion University, Norfolk, VA
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HEAT WAVES
STORMS
EARTHQUAKES
Haiti
Low Social Capital
New Orleans
Low Social capital
Hatii 2010
Earthquake
Magnitude: 7.0
Death Toll: 85,000 - 365,000
(Very large uncertainty)
%
Deaths per Day
5
10
15
20
25
30
Time in Days
A Science - Engineering - Policy Paradigm
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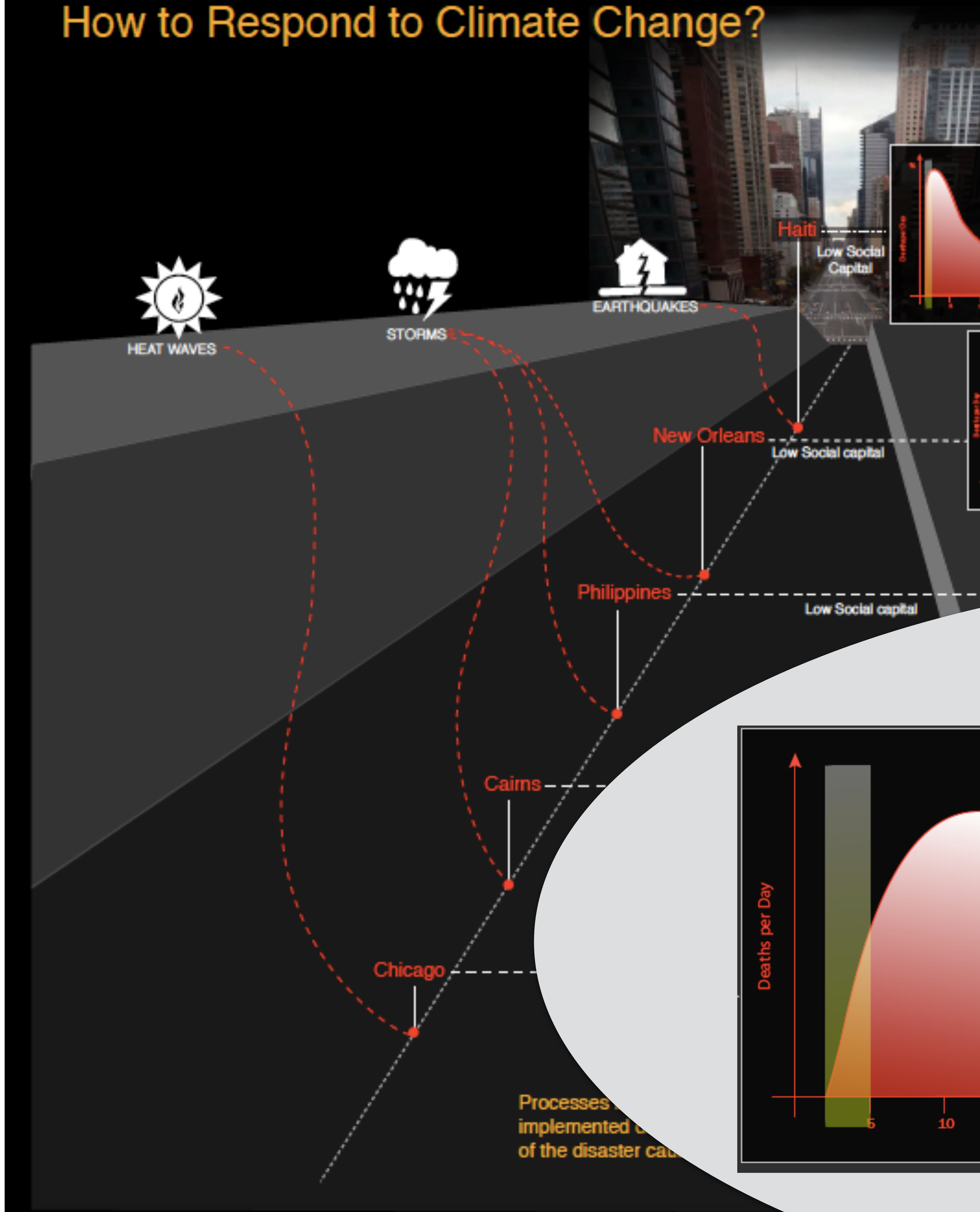
Deterministic or Probabilistic - Robustness or Resilience: How to Respond to Climate Change?



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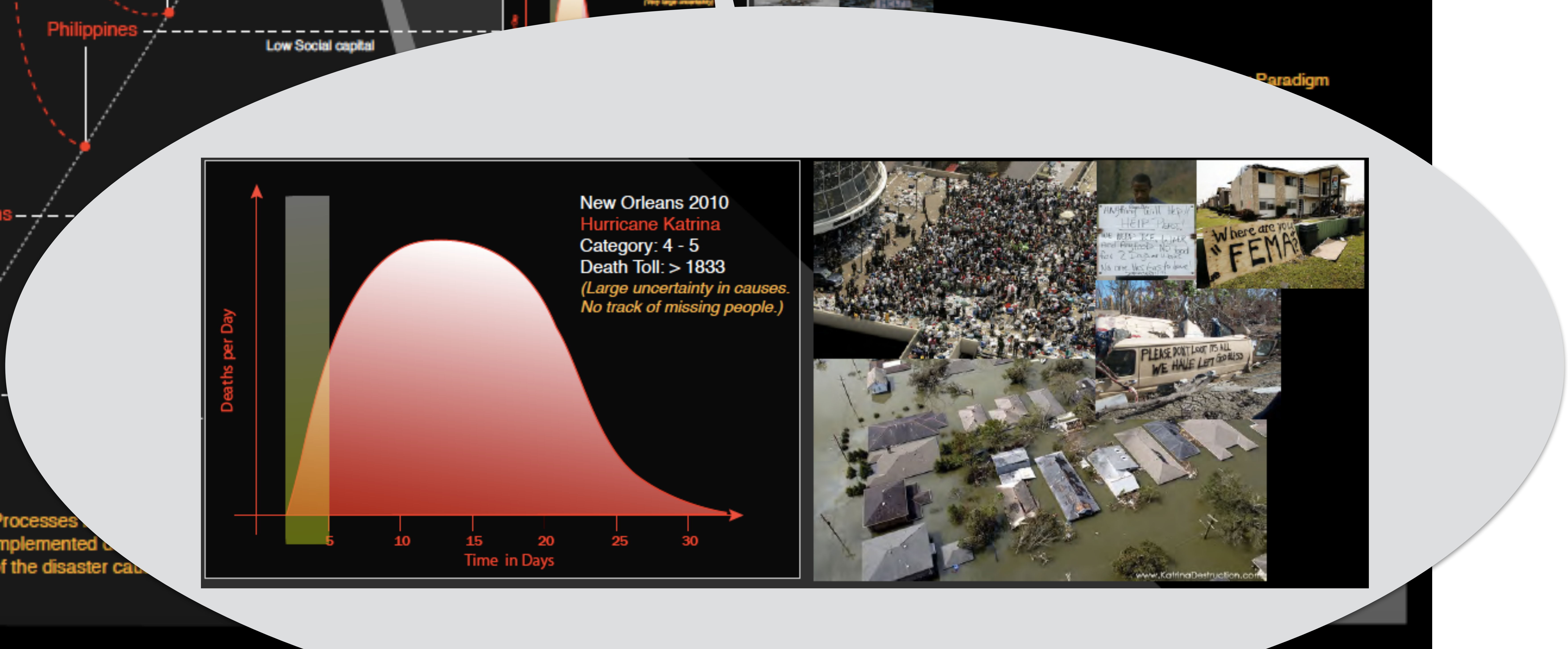
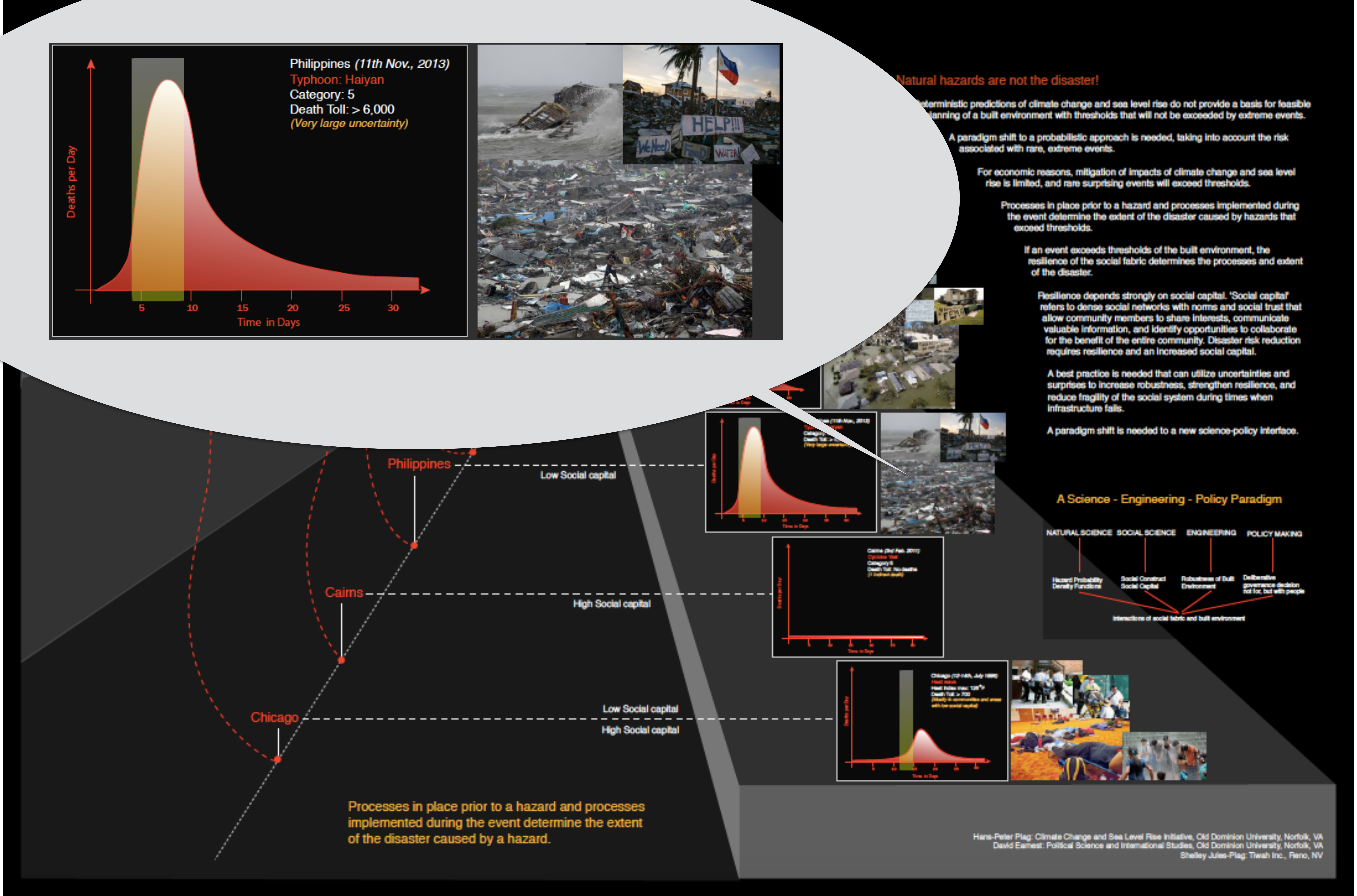
Paradigm





Philippines (11th Nov., 2013)
Typhoon: Haiyan
Category: 5
Death Toll: > 6,000
(Very large uncertainty)
Deaths per Day
5
10
15
20
25
30
Time in Days
HELP!!!
WATER
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Cairns
High Social capital
Chicago
Low Social capital
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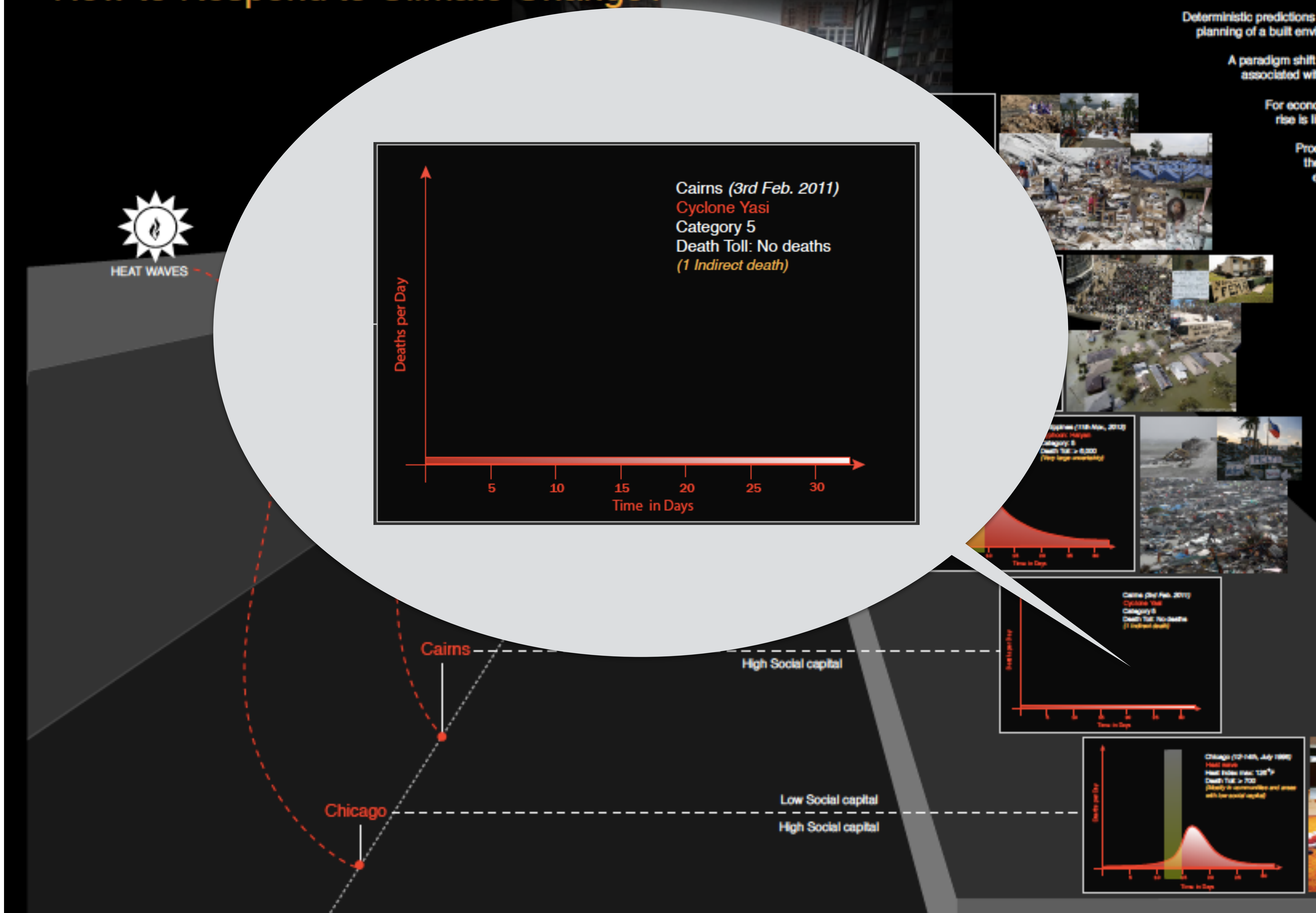
Deterministic or Probabilistic - Robustness or Resilience: How to Respond to Climate Change?



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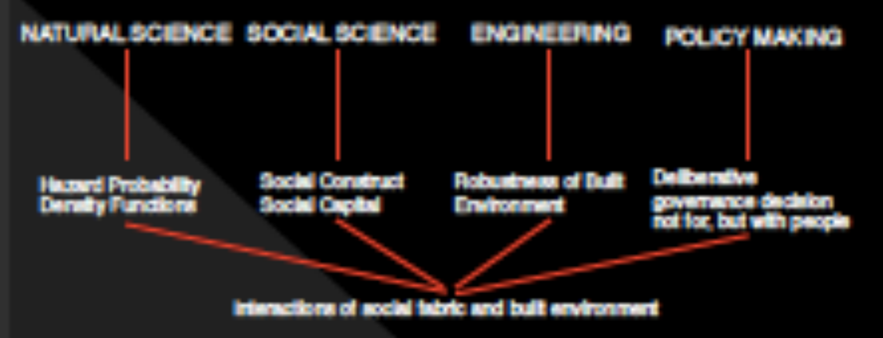
A Science - Engineering - Policy Paradigm



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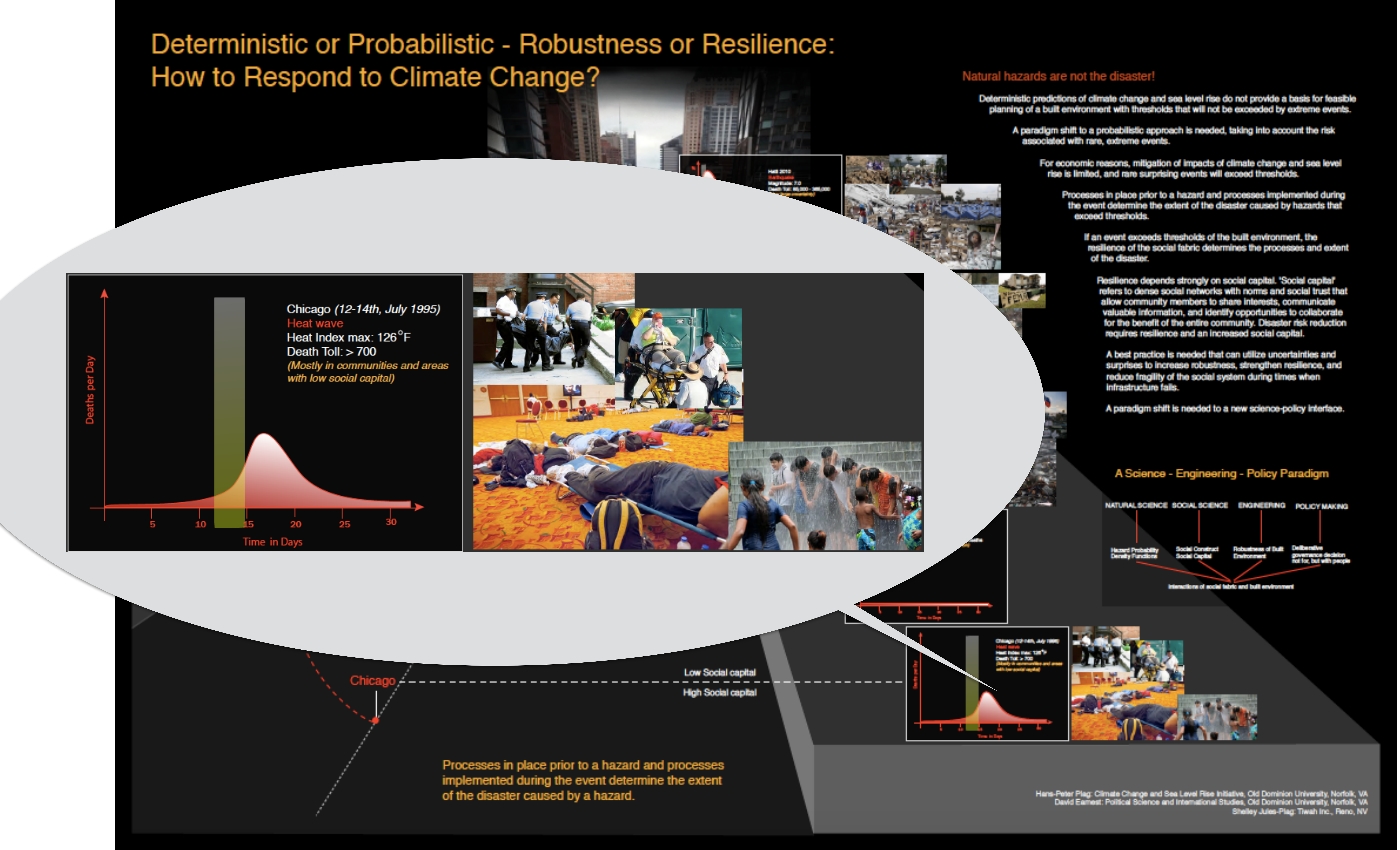

Deterministic or Probabilistic - Robustness or Resilience:
How to Respond to Climate Change?
Chicago (12-14th, July 1995)
Heat wave
Heat Index max: 126°F
Death Toll: > 700
(Mostly in communities and areas with low social capital)
Deaths per Day
5
10
15
20
25
30
Time in Days
Natural hazards are not the disaster!
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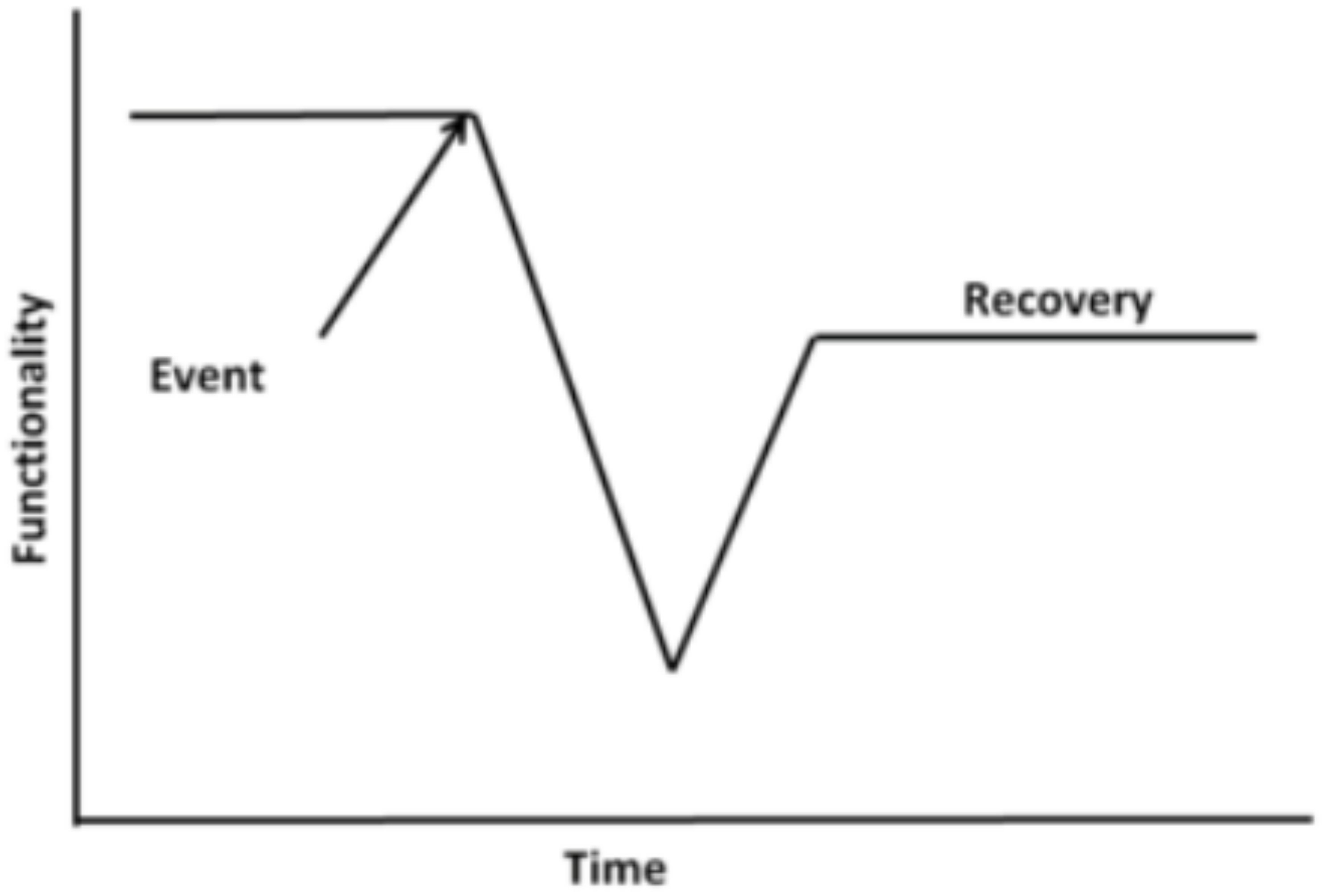
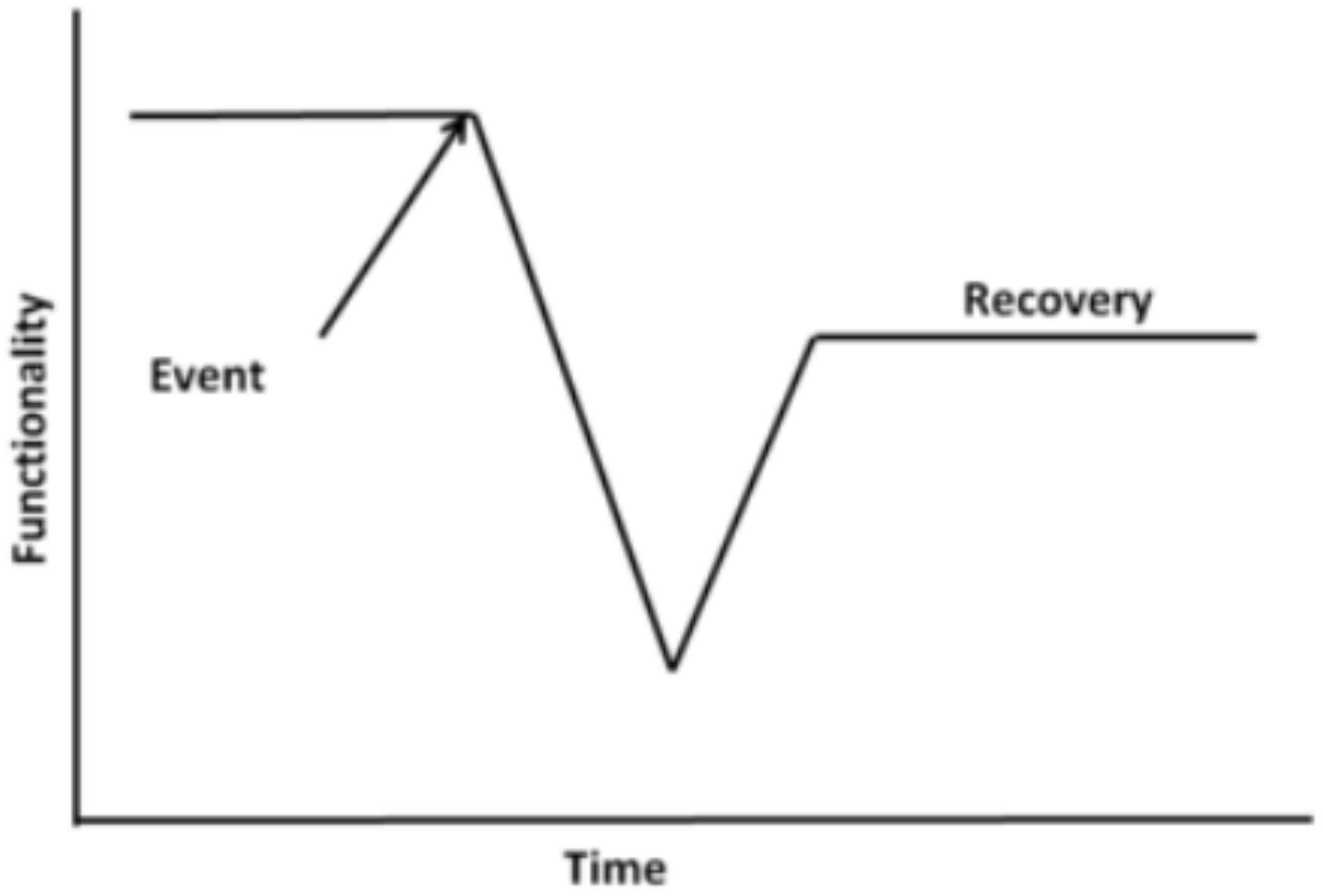
Terminology



Terminology

Resilience

"**Resilience is the act of rebounding or springing back**"
(Oxford English Dictionary, 1973)



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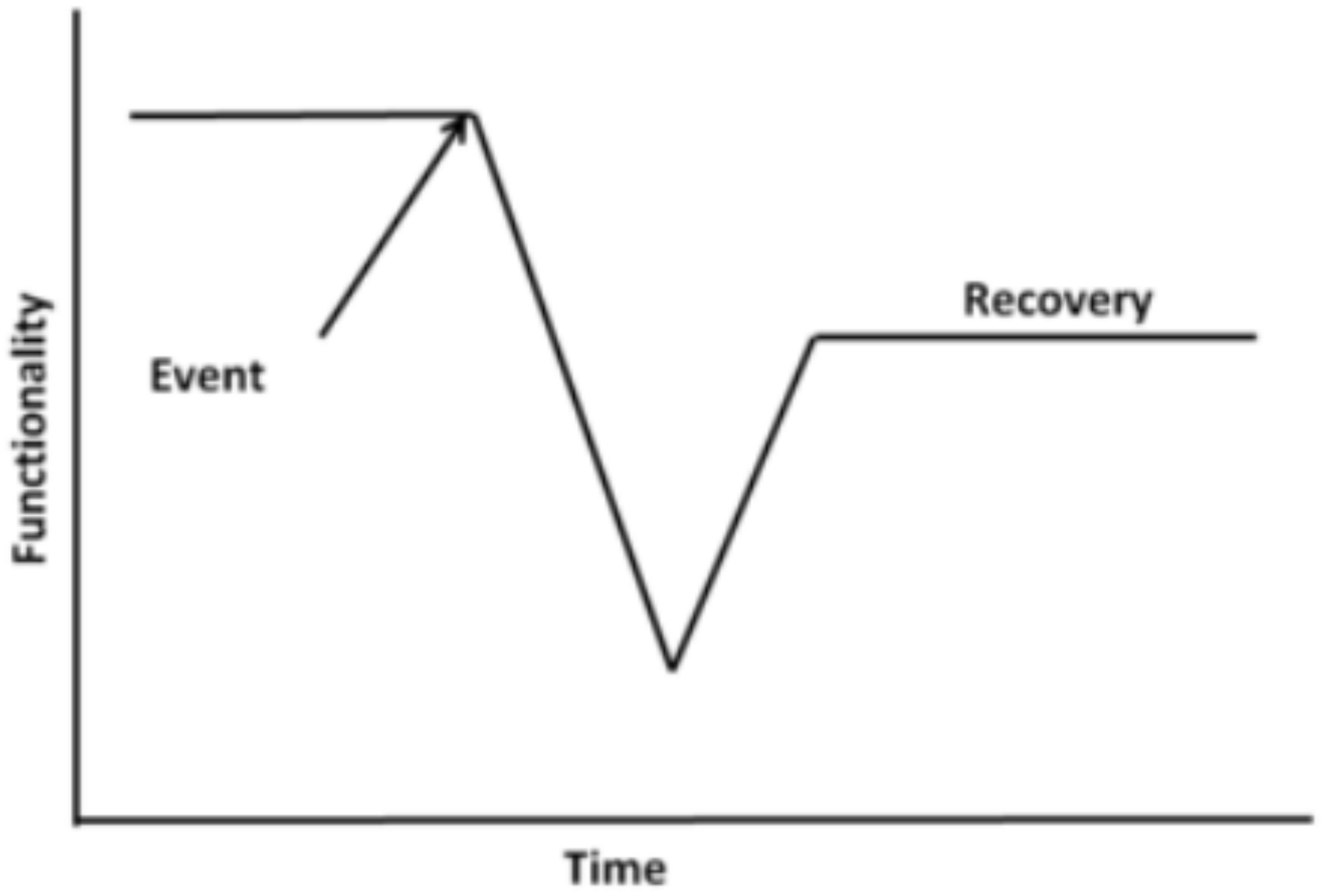
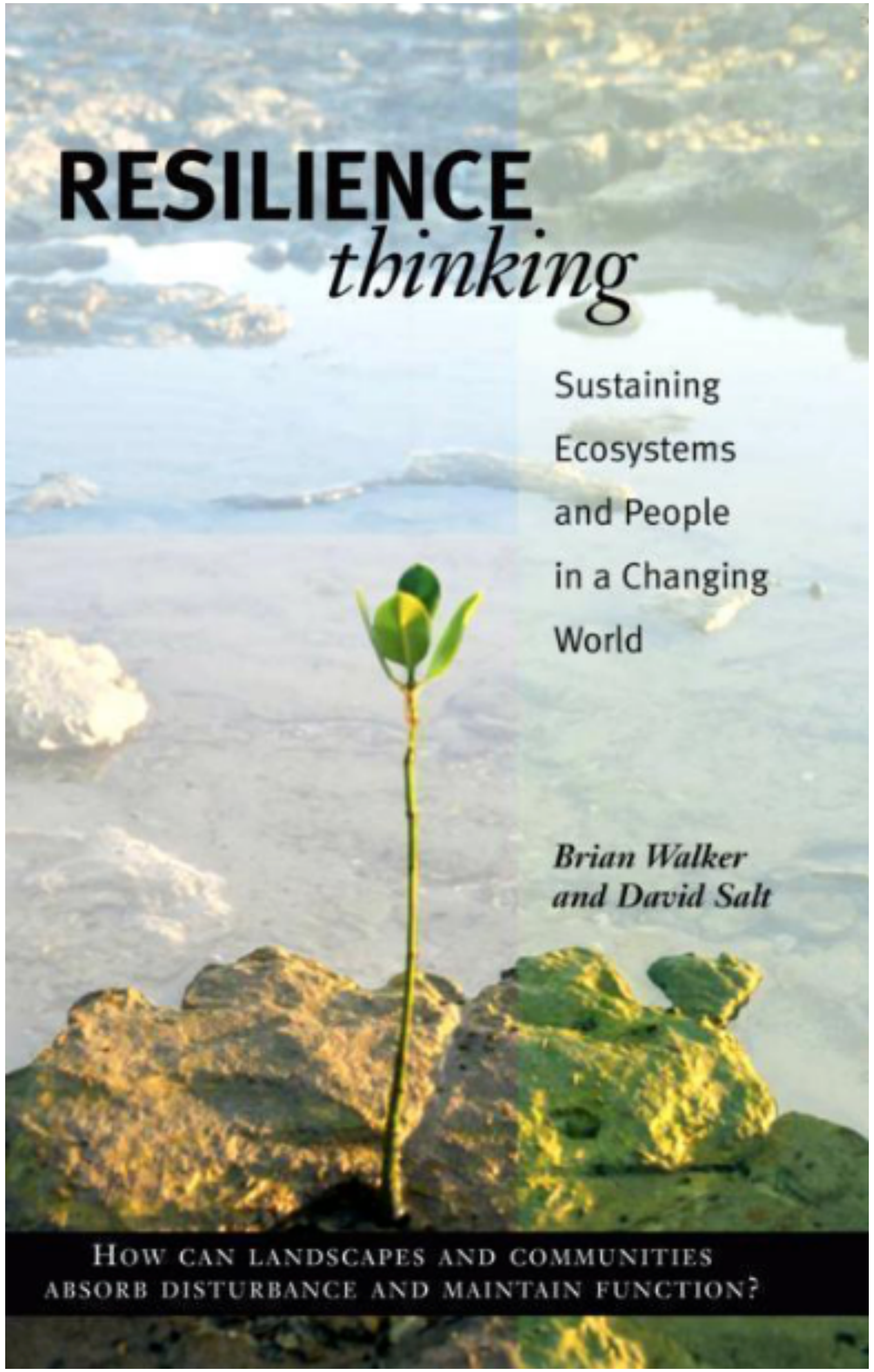
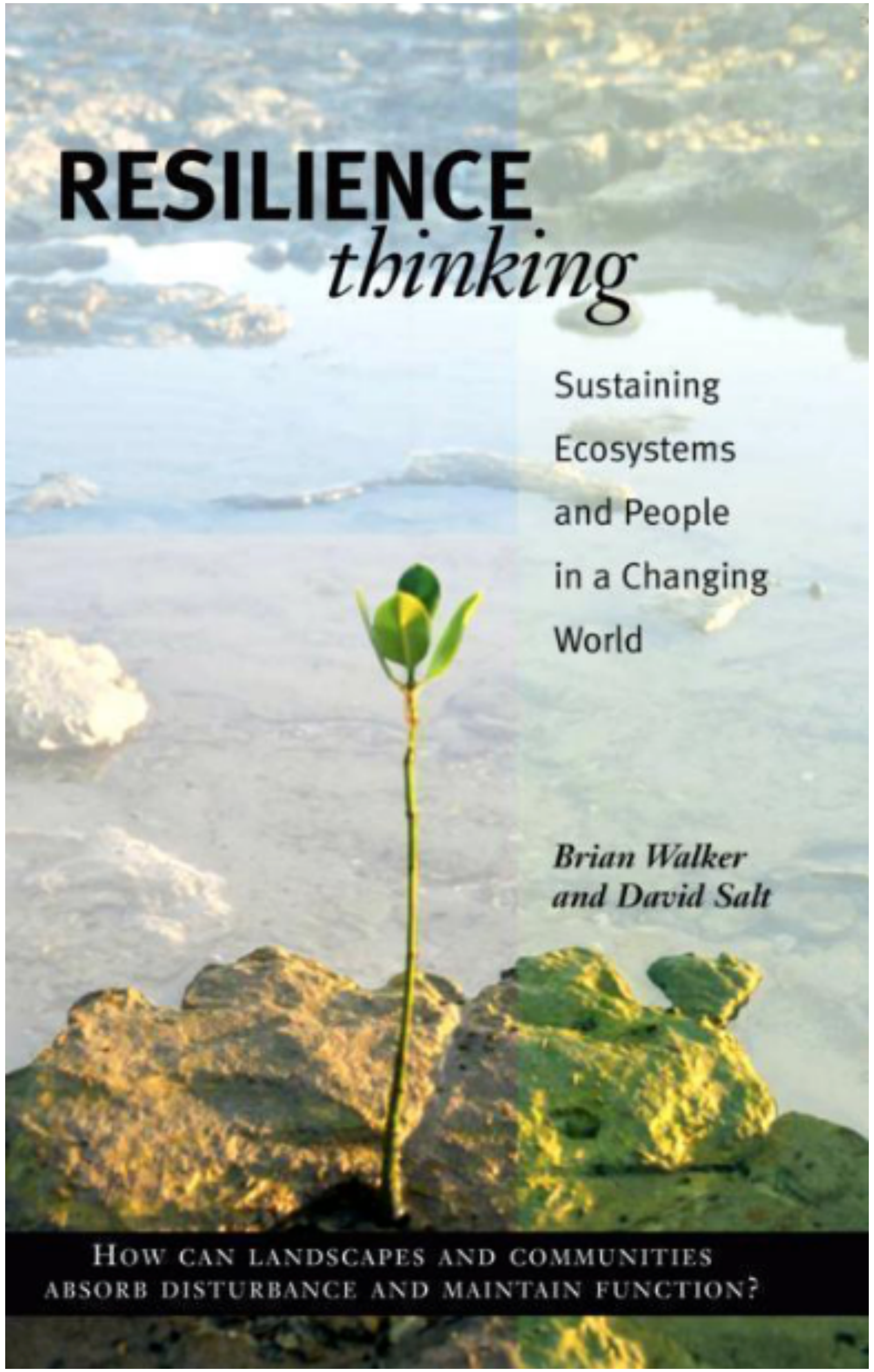


"Resilience is the **capacity of a system to absorb disturbance and still retain its basic function and structure**."

Brian Walker PhD. Resilience Thinking: Sustaining Ecosystems and People in a Changing World (Kindle Locations 64-65). Kindle Edition.



Adaptive Cycles



Adaptive Cycles

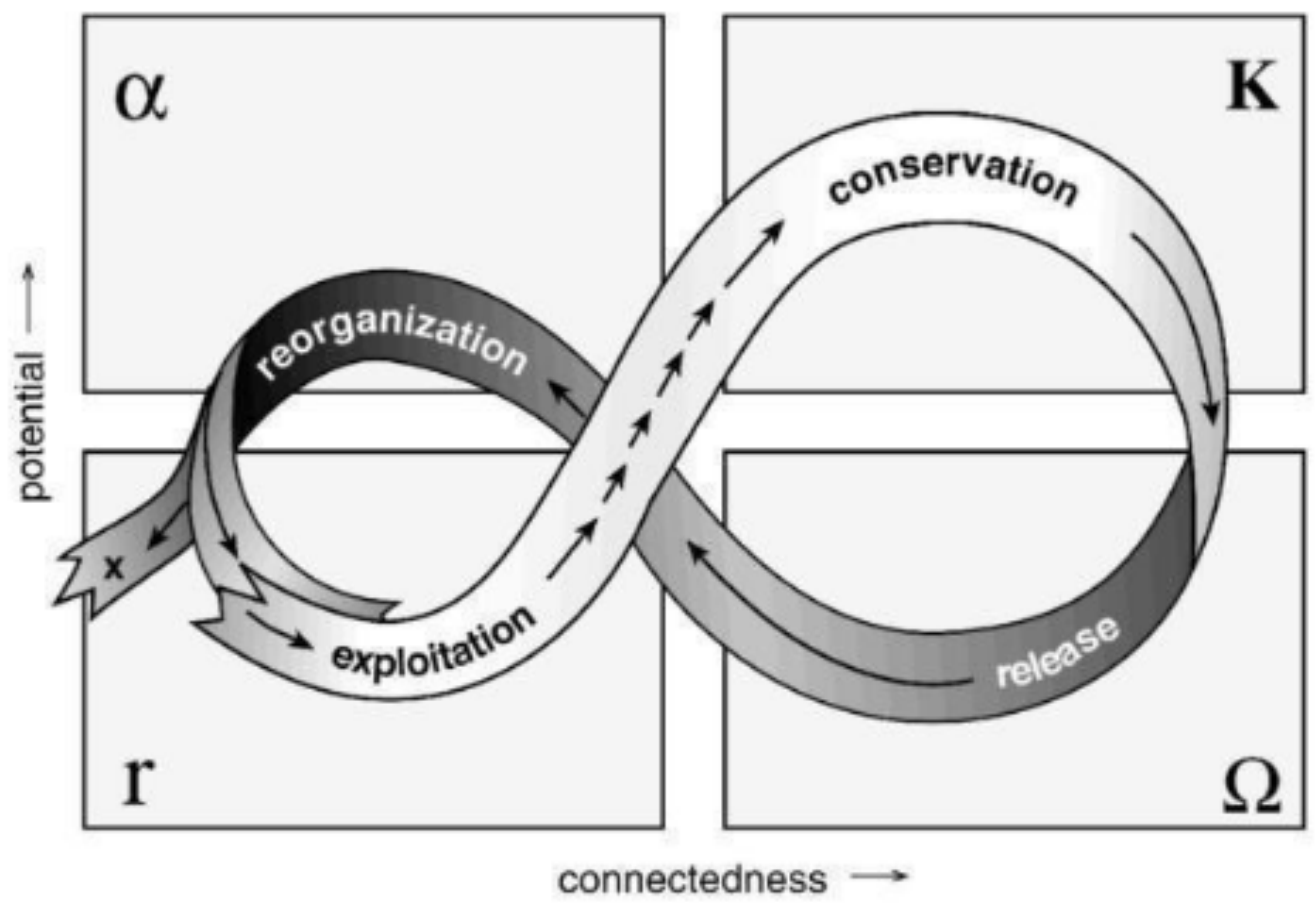
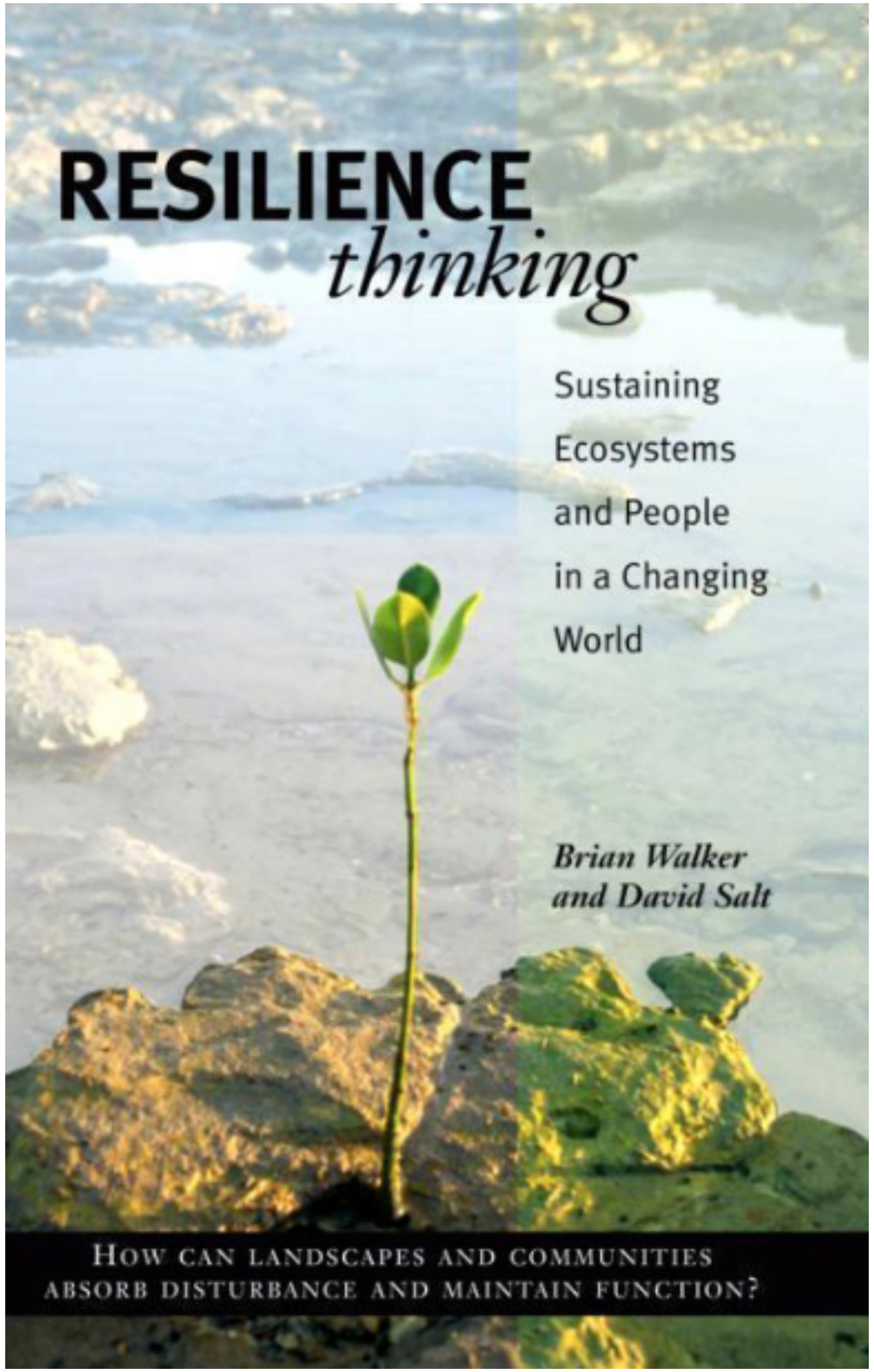


FIGURE 9 The First Version of the Adaptive Cycle

The first versions of the adaptive cycle pictured it as a figure 8 in two dimensions with the axes being connectedness and potential. Potential reflects accumulated growth and storage (biomass that is increasingly inactive like heartwood in trees or leaf litter). The use of the simpler loop, as shown in figure 10, has been adopted because it better reflects the passage from release to reorganization in some systems. However, because the adaptive cycle in the shape of the number 8 (as shown here in figure 9) was the original version it has iconic value, and it is often seen as a symbol of studies on resilience and adaptive cycles. *(From Gunderson and Holling, 2002)*



Adaptive Cycles

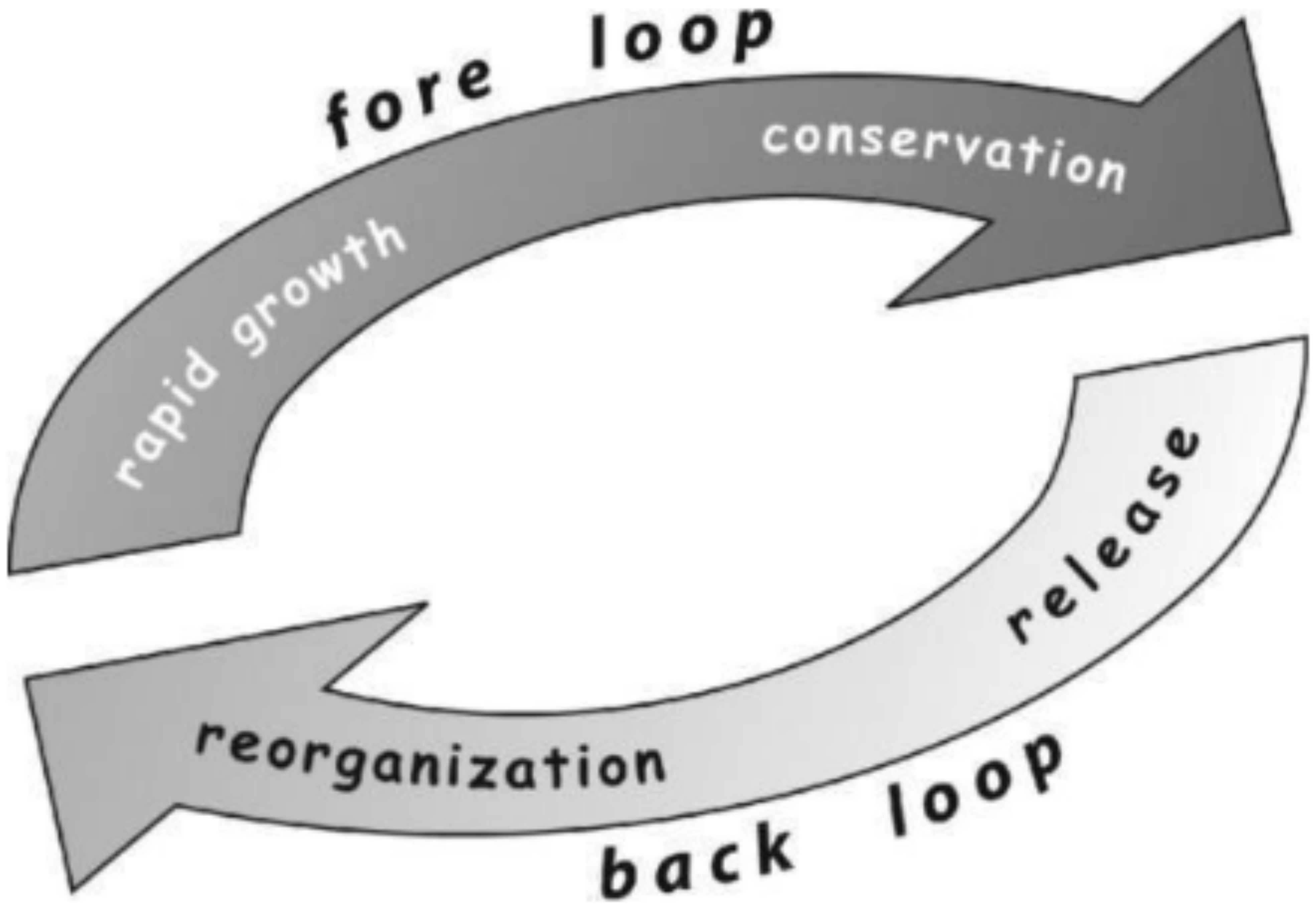
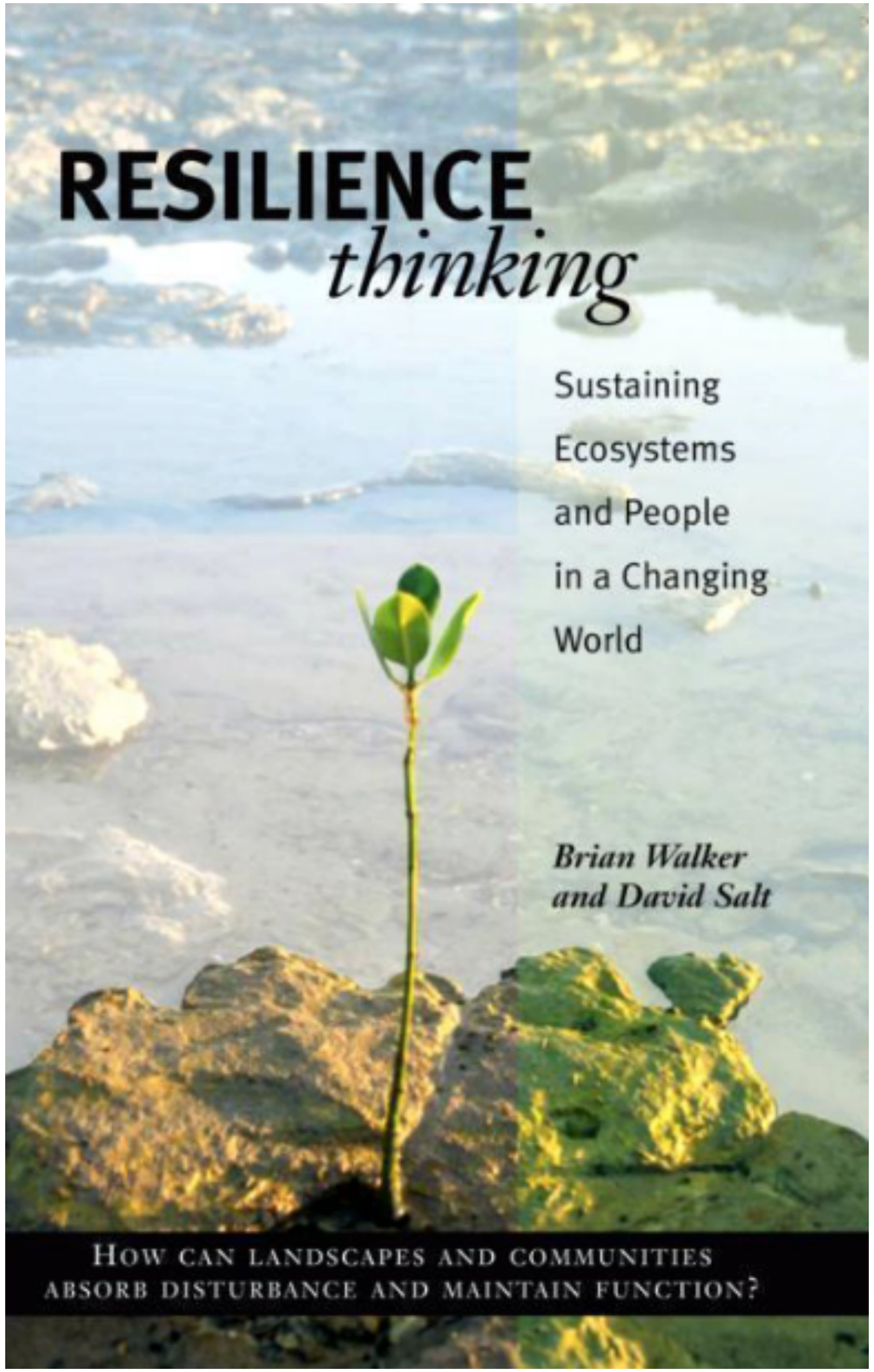


FIGURE 10 A Simple Representation of the Adaptive Cycle

The rapid growth and conservation phases are referred to as the fore loop with relatively predictable dynamics and in which there is a slow accumulation of capital and potential through stability and conservation. The release and reorganization phases are referred to as the back loop, characterized by uncertainty, novelty, and experimentation and during which there is a loss (leakage) of all forms of capital. The back loop is the time of greatest potential for the initiation of either destructive or creative change in the system.



Adaptive Cycles

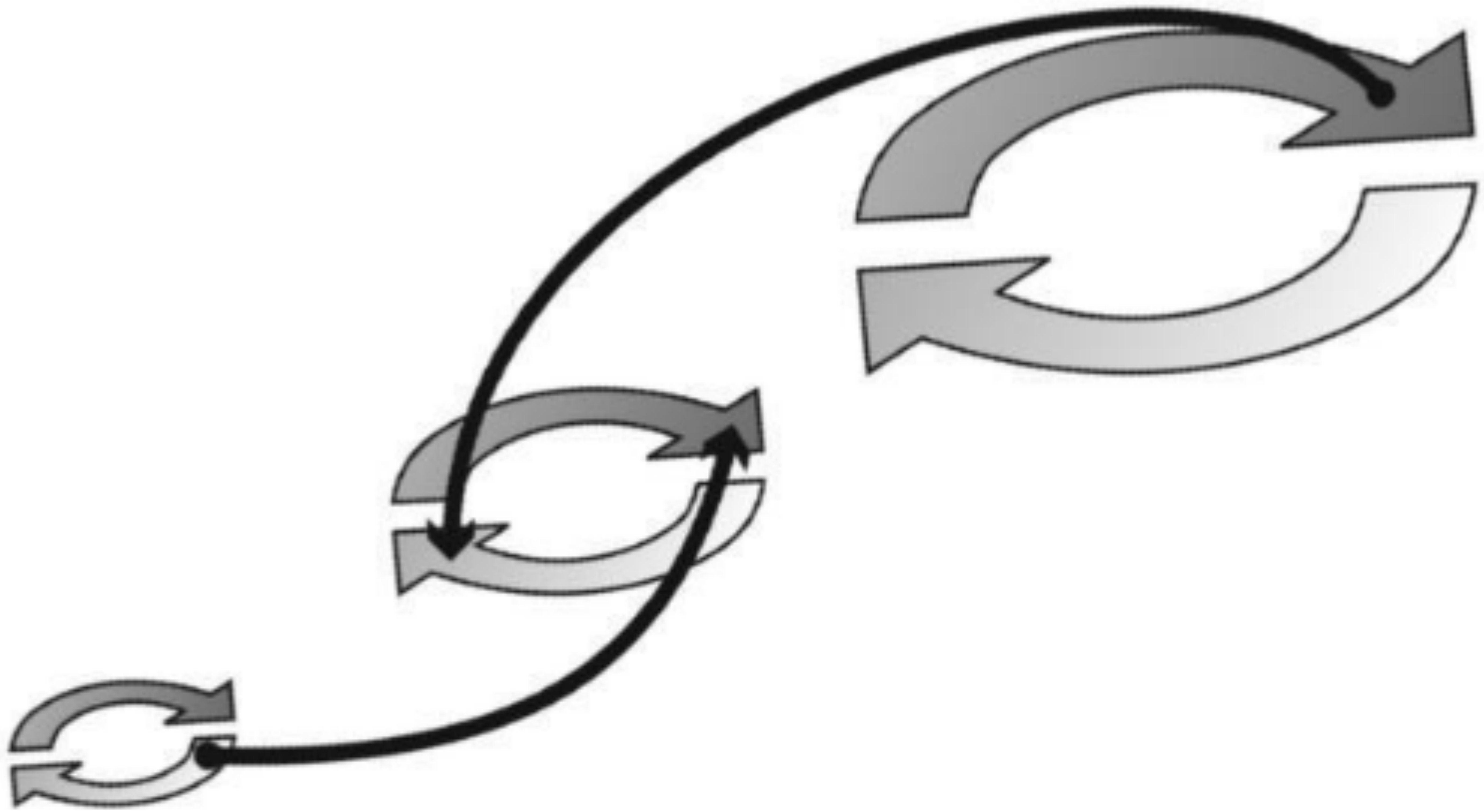
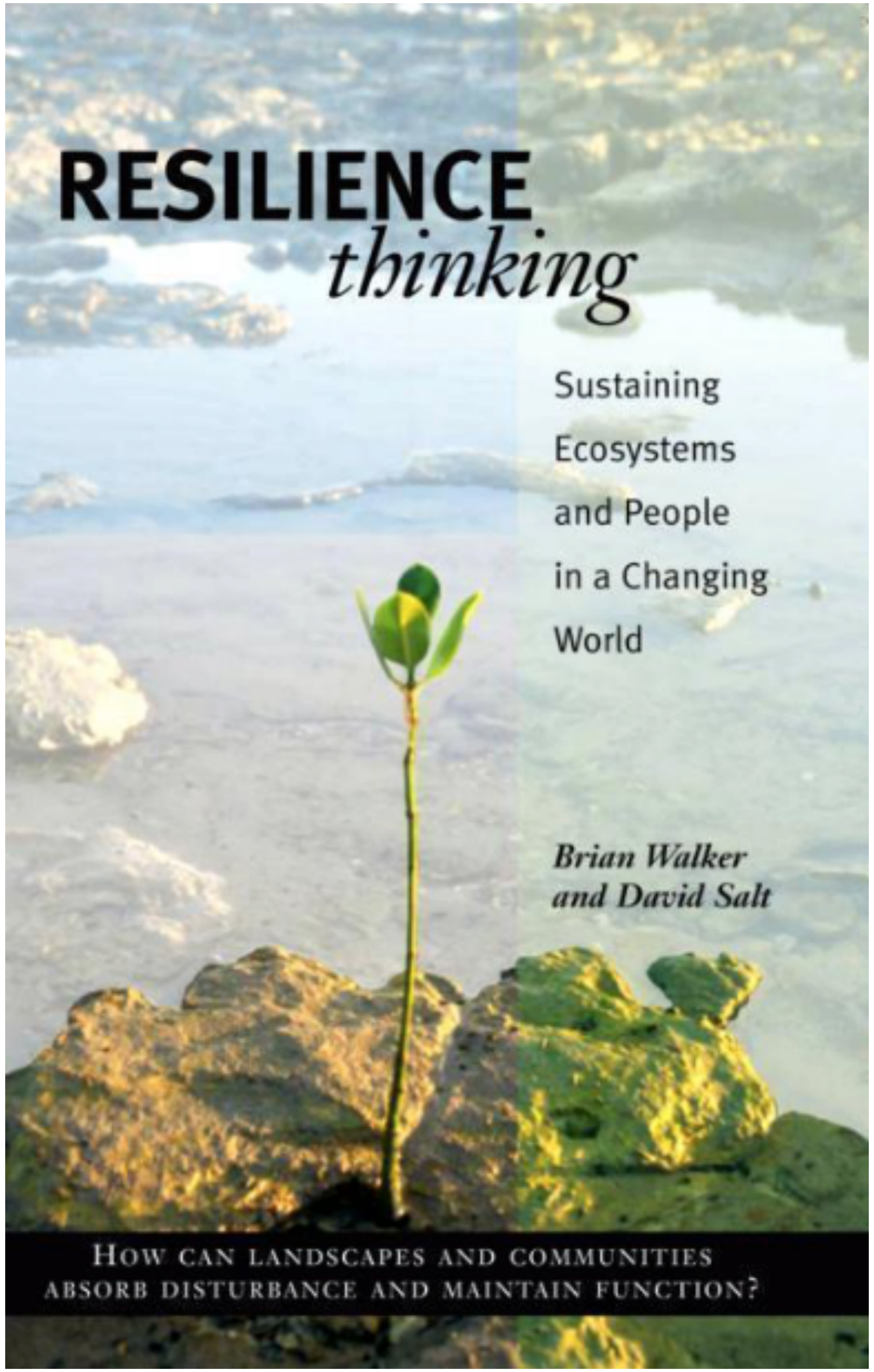
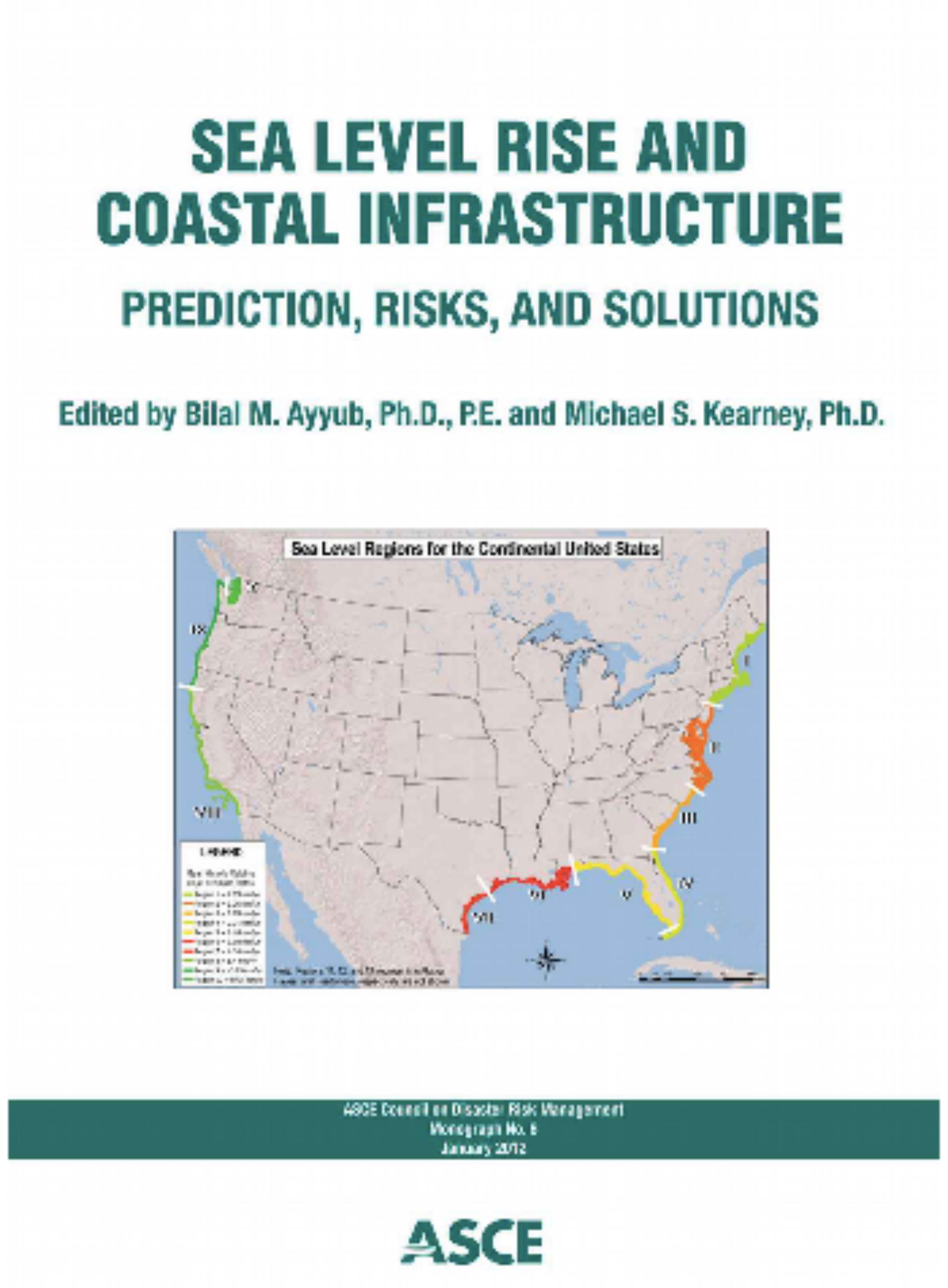


FIGURE 13 Panarchy Refers to Hierarchies of Linked Adaptive Cycles



Terminology

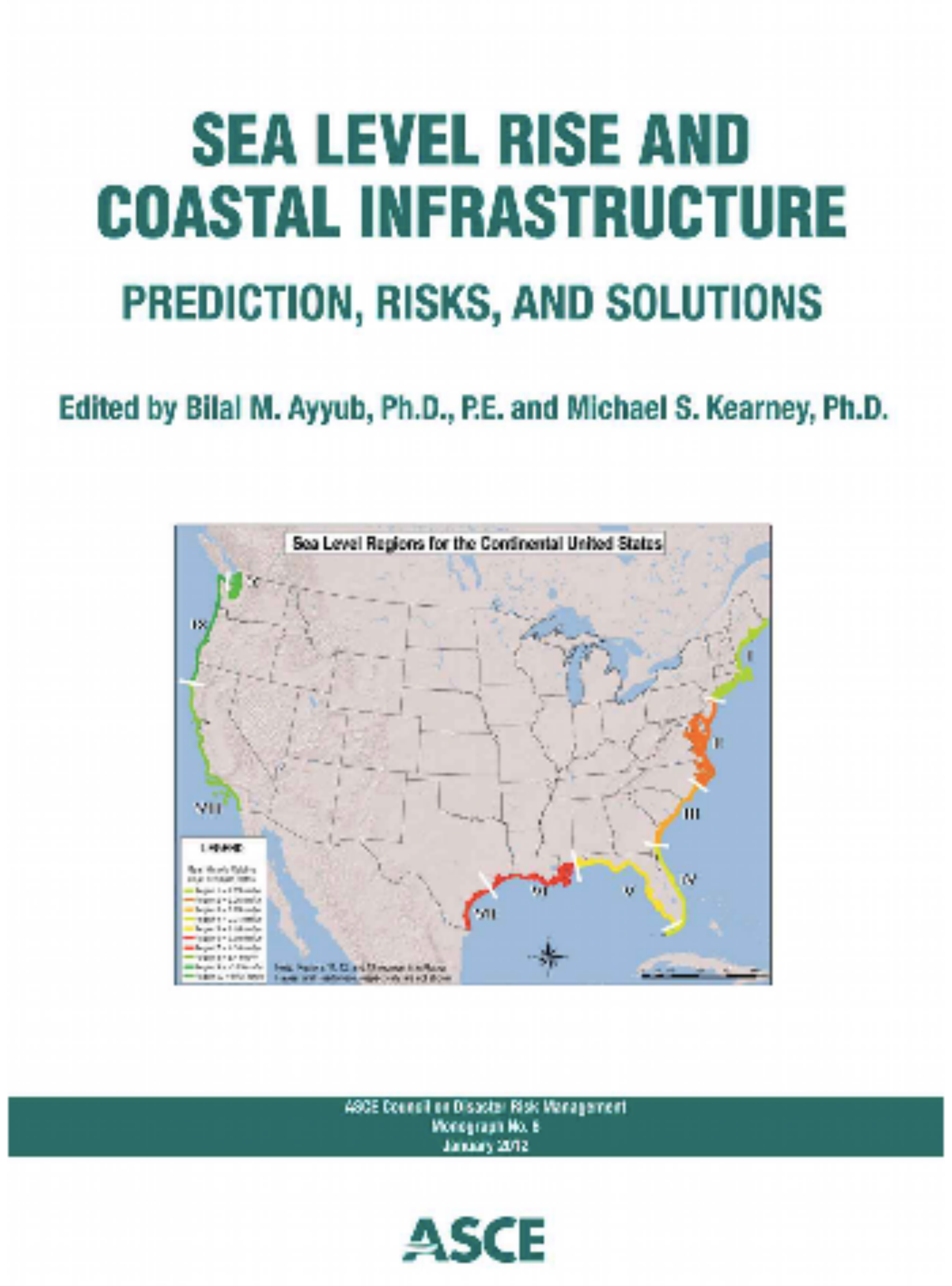
Resilient and Adaptive Systems



Resilient and Adaptive Systems

Resilient systems **bend under stress but do not break,** so they are able to weather storms more effectively and recover more quickly. **Adaptive systems are characterized by redundancy, diversity, efficiency, strength, interdependence, adaptability, and collaborativeness** (Godschalk 2003). They are designed so that the failure of one part does not cause the whole system to collapse.

Ayyub, Bilal M.. Sea Level Rise and Coastal Infrastructure: Prediction, Risks, and Solutions (Council on Disaster Risk Management (CDRM) Monograph) (Kindle Locations 2359-2361). American Society of Civil Engineers. Kindle Edition.



Resilient and Adaptive Systems

Resilient and Adaptive Systems

"I want to reserve resilience to refer to the broader capability – how well can a system handle **disruptions and variations that fall outside of the base mechanisms/model for being adaptive** as defined in that system."

Hollnagel in Woods, D. D. Resilience Engineering: Concepts and Precepts (Kindle Locations 487-488). Ashgate Publishing Ltd. Kindle Edition.

However, we would argue that we should extend the definition a little more broadly, in order to **encompass also the ability to avert the disaster or major upset**, using these same characteristics. Resilience then describes also the characteristic of managing the organisation's activities to **anticipate and circumvent threats** to its existence and primary goals. This is shown in particular in an ability to manage severe pressures and conflicts between safety and the primary production or performance goals of the organisation.

Hale & Heijer, in Woods, D. D. Resilience Engineering: Concepts and Precepts (Kindle Locations 728-732). Ashgate Publishing Ltd. Kindle Edition.

Terminology

Thresholds and Resilience Thinking

Thresholds and the adaptive cycle metaphor are both central to resilience thinking. Adaptive cycles describe how many systems behave over time, and how resilience varies according to the phase where the system lies. **Thresholds represent transitions between alternate regimes**. While the two concepts can sometimes be related in the pattern of a particular system's dynamics, this not always the case. They are different models used for different purposes, and it is not always possible to equate the dynamics of a basin of attraction with the dynamics of an adaptive cycle. Where they do coincide, however, alternate regimes generally represent a new adaptive cycle, indicating that the system has new structures and feedbacks.

Brian Walker PhD. Resilience Thinking: Sustaining Ecosystems and People in a Changing World (Kindle Locations 1168-1170). Kindle Edition.

Terminology

Terminology

Thresholds

In a system, a **threshold** is a point at which a relatively small change or disturbance causes a rapid change in the system.

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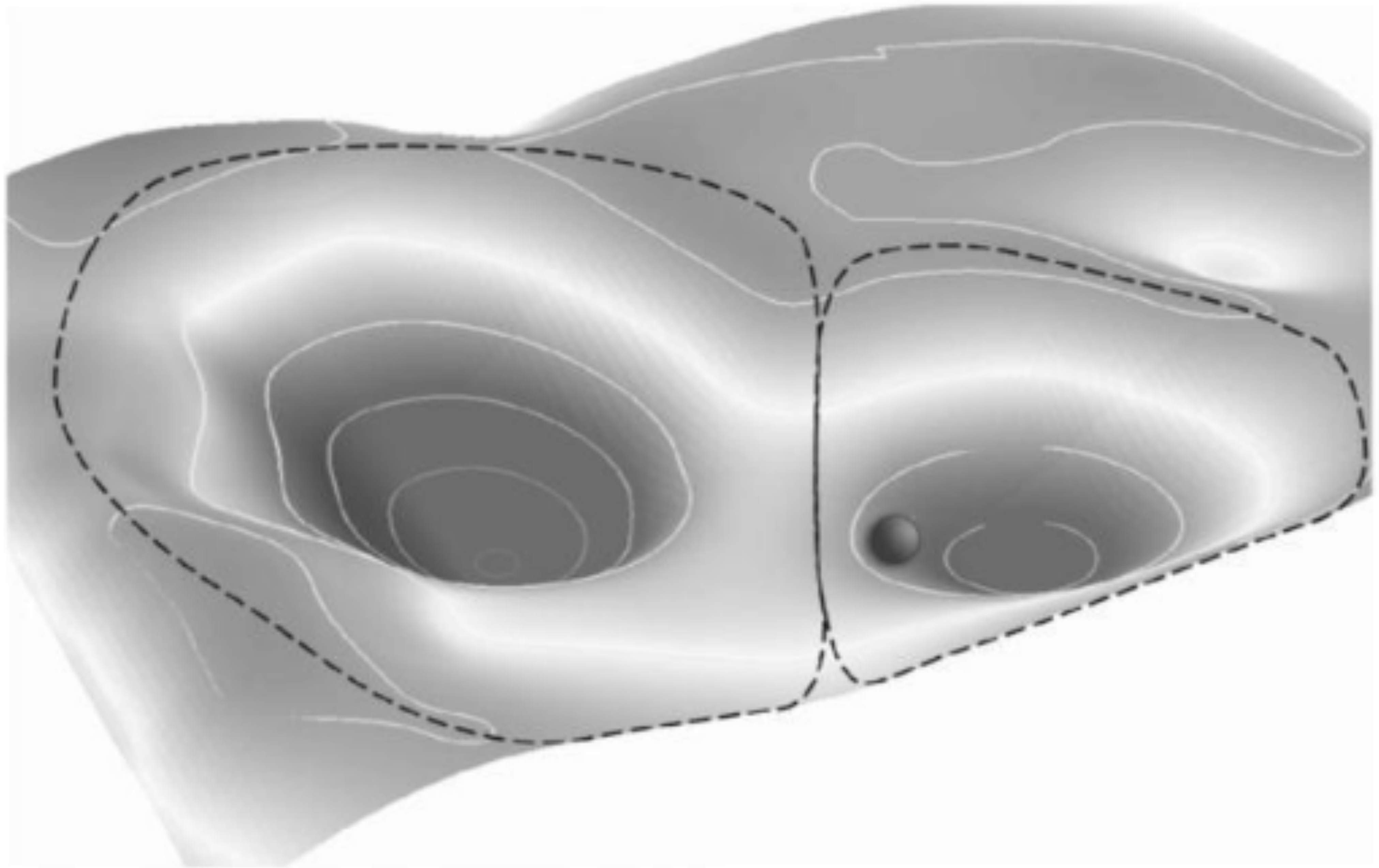


FIGURE 3 The System as a Ball-in-the-Basin Model

The ball is the state of the social-ecological system. The basin in which it is moving is the set of states which have the same kinds of functions and feedbacks, resulting in the ball moving towards the equilibrium. The dotted line is a threshold separating alternate basins. *(From Walker et al , 2004)*

Thresholds

In a system, a **threshold** is a point at which a relatively small change or disturbance causes a rapid change in the system.

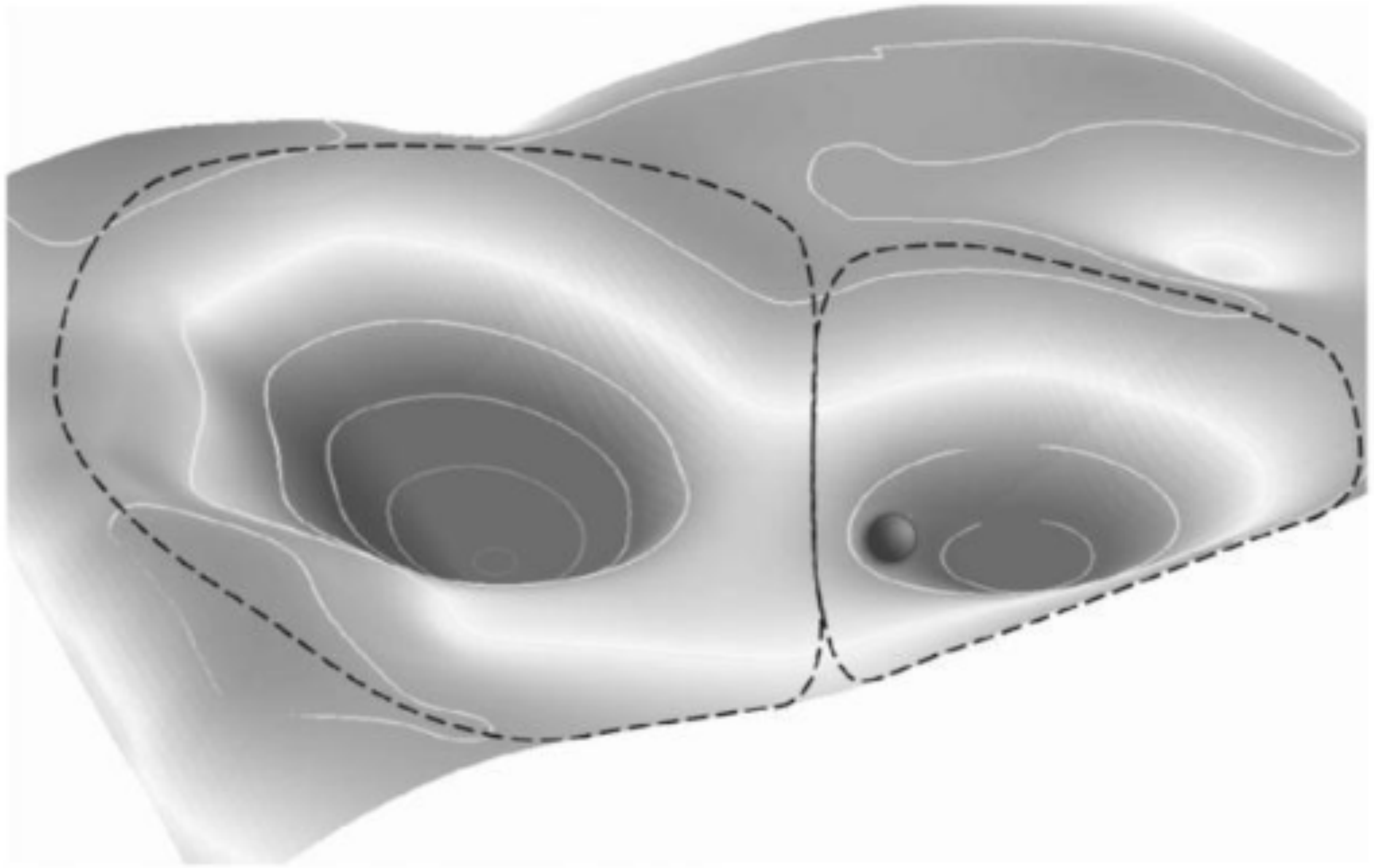


FIGURE 3 The System as a Ball-in-the-Basin Model

The ball is the state of the social-ecological system. The basin in which it is moving is the set of states which have the same kinds of functions and feedbacks, resulting in the ball moving towards the equilibrium. The dotted line is a threshold separating alternate basins. *(From Walker et al , 2004)*

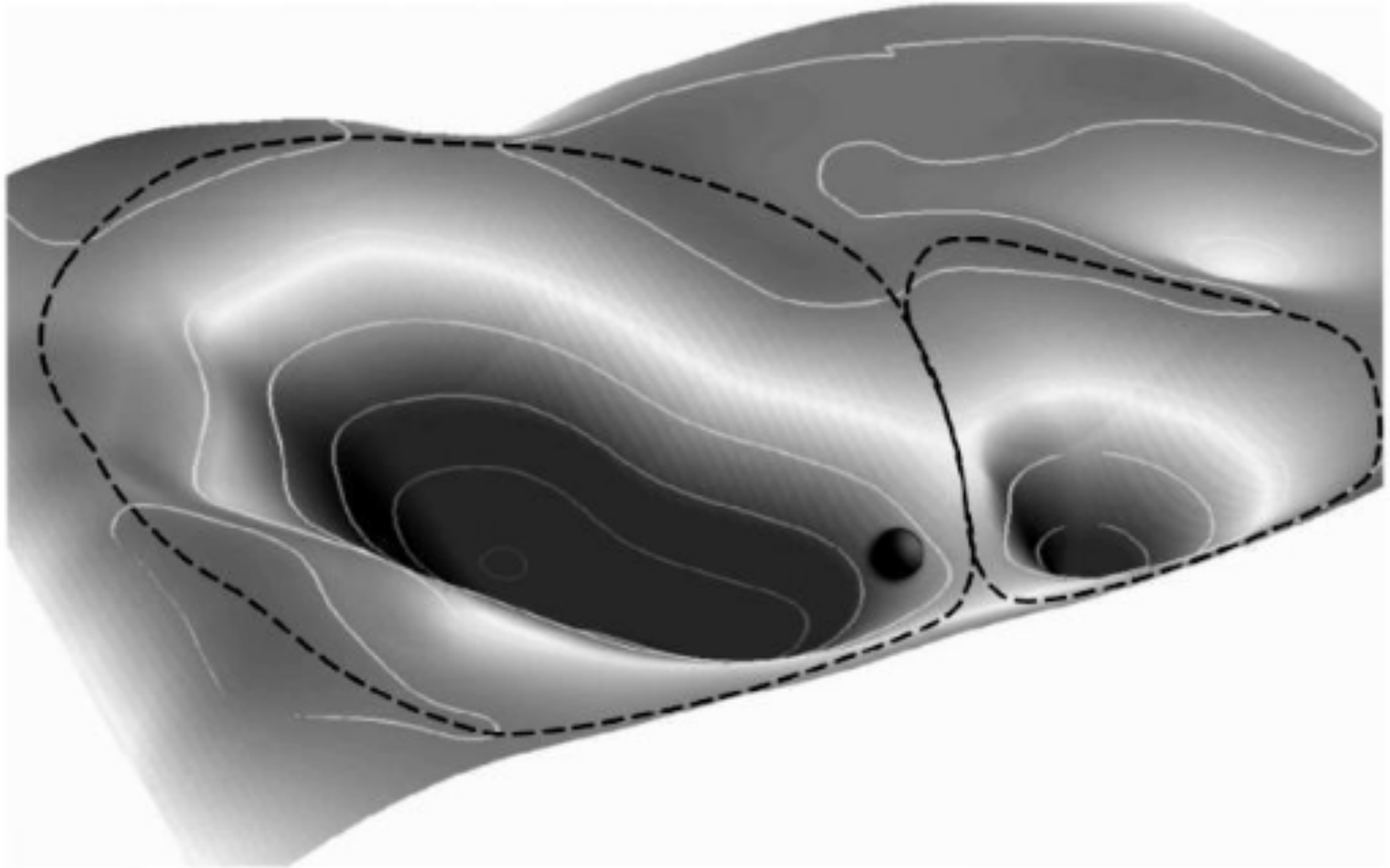


FIGURE 4 The Basin Changes Shape

This this is the same system as in figure 3. The state of the system (position of the ball) has not changed, but as conditions change, so too does the shape of the basin and the behavior of the system. *(From Walker et al , 2004.)*

Thresholds

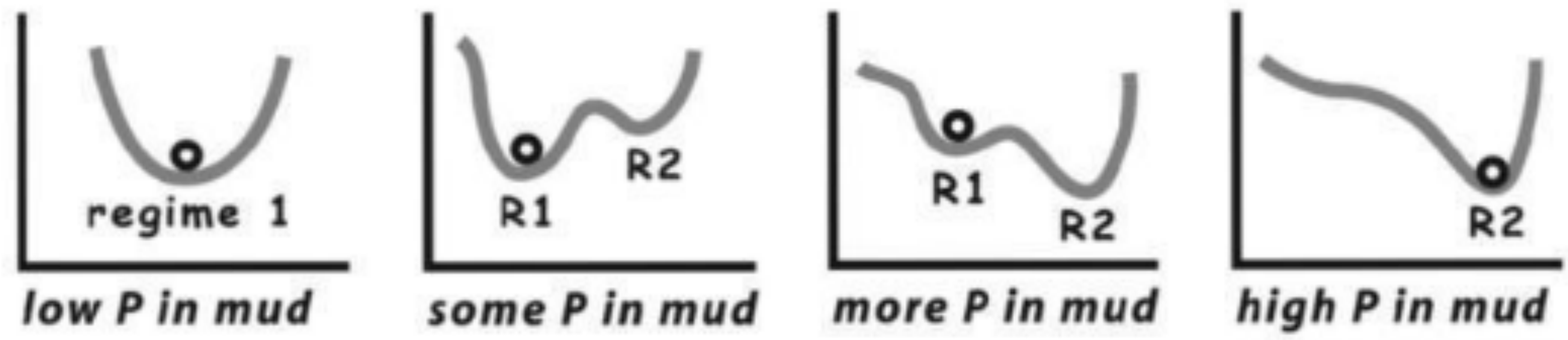
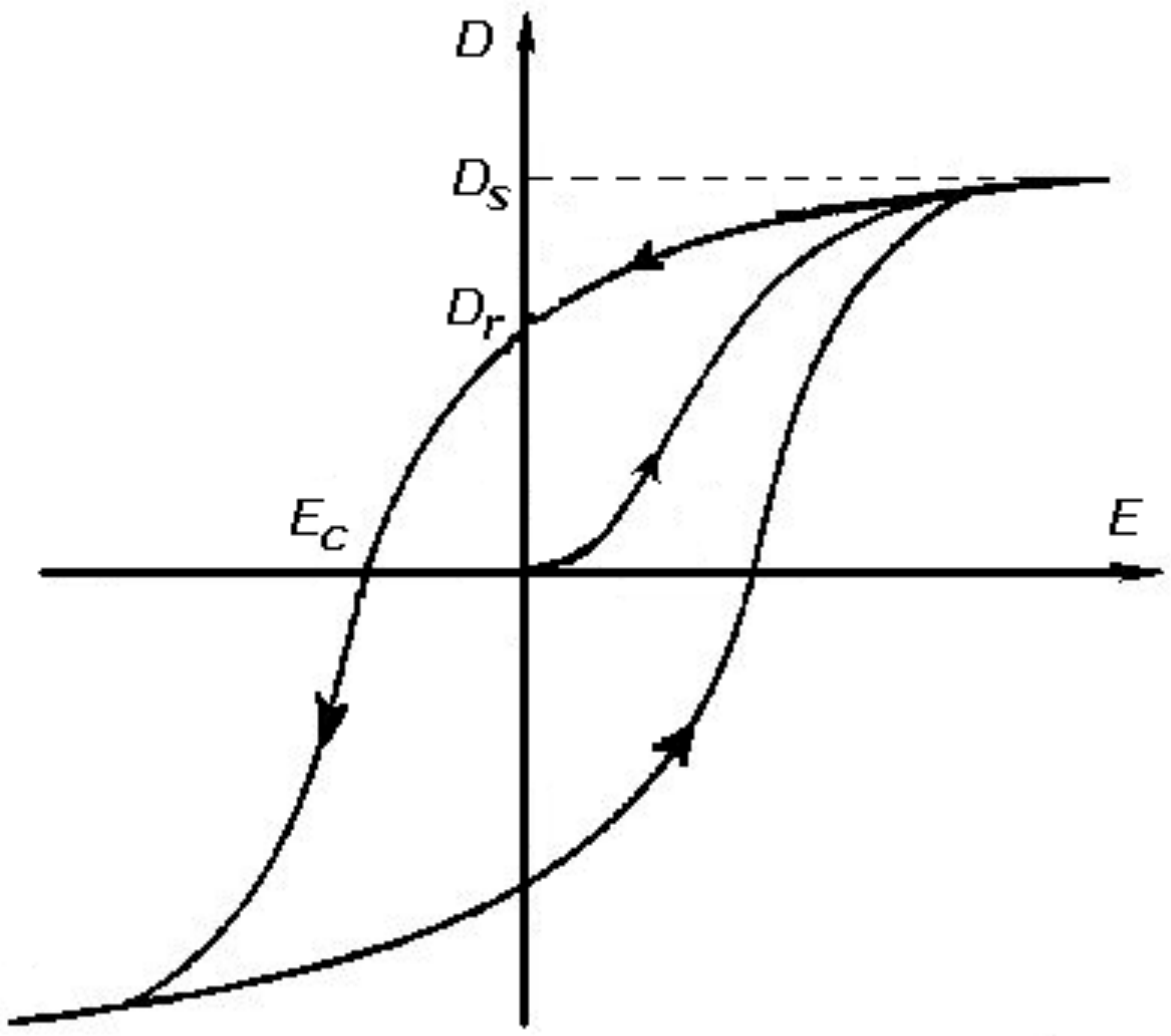


FIGURE 5 A Two-Dimensional Representation of a Ball-in-a-Basin Model of a Lake Ecosystem Changing over Time with Continued Phosphorus Inputs

Terminology

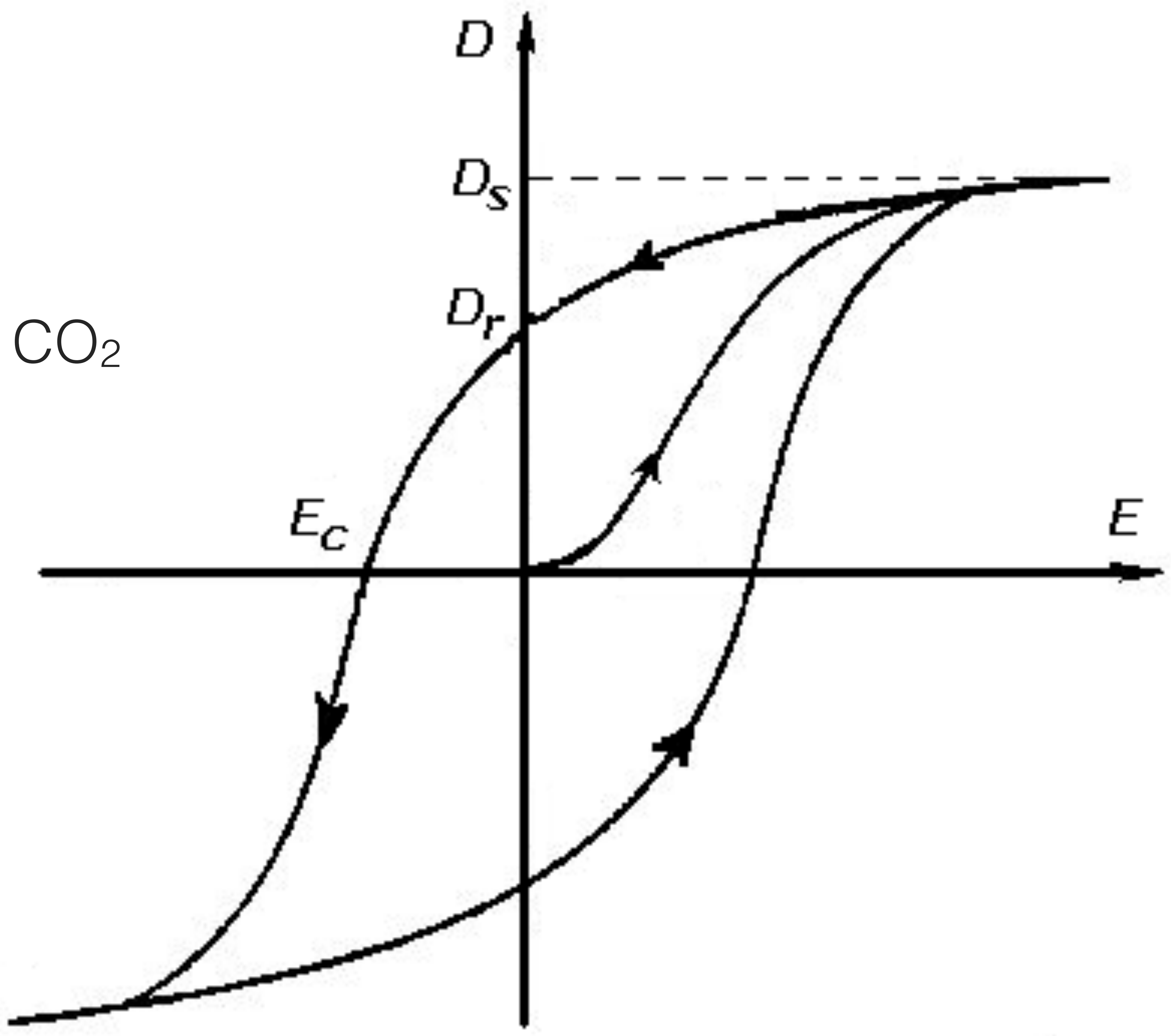


Terminology

Hysteresis: state of the system depends on both the presence and the past history.

Examples:

- post-glacial deformation as function of ice load
- global air temperature as function of atmospheric CO_2
- ecosystem as function of disturbances



Electromagnetic Displacement Field *D* as function of the electrical field *E*.

Summary

Risk: static, event based loss

Summary

Risk: static, event based loss

Risk reduction —-> risk governance

Summary

Risk: static, event based loss

Risk reduction —-> risk governance

Resilience: response to disturbance

Summary

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Increasing Resilience —> Resilience governance: cycles, panarchy

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Thresholds: (rapid) shift in system state

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No concept for handling thresholds

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Change: slow drift of system to a new state

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Mitigation: reducing the potential for change

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Thresholds: (rapid) shift in system state

No concept for handling thresholds

Change: slow drift of system to a new state

Mitigation: reducing the potential for change

Adaptation: responding to, or preparing for change

Anti-fragile: learning from disturbances and impacts

Vulnerabilities

Vulnerabilities

Figure 2 presents the full list of climate change risks and opportunities considered in the assessment. These include the exposure of interdependent infrastructure networks to multiple, correlated hazards (e.g. flooding and high winds), as well as the vulnerability of certain infrastructure types to specific hazards (e.g. road surfaces to high temperatures). Air quality in both urban and rural areas could deteriorate further though climate change will have less influence than pollution from transport, industry and farming. Risks will arise for culturally-valued buildings and landscapes from a combination of higher temperatures and rainfall intensities. There are also uncertain but potentially very significant international risks arising from climate-related human displacement, and the possibility of violent inter state conflict over scarce natural resources.

Figure 2: Urgency categories for climate change risks and opportunities for the UK

MORE ACTION NEEDED	RESEARCH PRIORITY	SUSTAIN CURRENT ACTION	WATCHING BRIEF
Ne1: Risks to species and habitats from changing climate space	Ne3: Changes in suitability of land for agriculture & forests	Ne9: Risks to agriculture, forestry, landscapes & wildlife from pests/pathogens/invasive species	Ne14: Risks & opportunities from changes in landscape character
Ne2: Opportunities from new species colonisations	Ne7: Risks to freshwater species from high water temperatures	Ne10: Extreme weather/wildfire risks to farming, forestry, wildlife & heritage	In7: Low/high riverflow risks to hydroelectric generation
Ne4: Risks to soils from increased seasonal aridity and wetness	Ne13: Ocean acidification & higher water temperature risks for marine species, fisheries and marine heritage	Ne11: Saltwater intrusion risks to aquifers, farmland & habitats	In8: Subsidence risks to buried/ surface infrastructure
Ne5: Risks to natural carbon stores & carbon sequestration	In5: Risks to bridges and pipelines from high river flows/erosion	In13: Extreme heat risks to rail, road, ICT and energy infrastructure	In10: Risks to electricity generation from drought and low flows
Ne6: Risks to agriculture & wildlife from water scarcity & flooding	In11: Risks to energy, transport & ICT from high winds & lightning	In14: Benefits for infrastructure from reduced extreme cold events	PB3: Opportunities for increased outdoor activity in warmer weather
Ne8: Risks of land management practices exacerbating flood risk	In12: Risks to offshore infrastructure from storms and high waves	PB13: Risks to health from poor water quality	PB12: Risks of food-borne disease cases and outbreaks
Ne12: Risks to habitats & heritage in the coastal zone from sea level rise; loss of natural flood protection	PB2: Risks to passengers from high temperatures on public transport	PB14: Risk of household water supply interruptions	Bu4: Risks to business from reduced access to capital
In1: Risks of cascading infrastructure failures across interdependent networks	PB6: Risks to viability of coastal communities from sea level rise	Bu3: Risks to business operations from water scarcity	Bu7: Business risks /opportunities from changing demand for goods & services
In2: Risks to infrastructure from river, surface/groundwater flooding	PB7: Risks to building fabric from moisture, wind, and driving rain	Bu6: Risks to business from disruption to supply chains	It7: Opportunities from changes in international trade routes
In3: Risks to infrastructure from coastal flooding & erosion	PB8: Risks to culturally valued structures and historic environment		
In4: Risks of sewer flooding due to heavy rainfall	PB10: Risks to health from changes in air quality		
In6: Risks to transport networks from embankment failure	PB11: Risks to health from vector-borne pathogens		
In9: Risks to public water supplies from drought and low river flows	Bu2: Risks to business from loss of coastal locations & infrastructure		
PB1: Risks to public health and wellbeing from high temperatures	Bu5: Employee productivity impacts in heatwaves and from severe weather infrastructure disruption		
PB4: Potential benefits to health & wellbeing from reduced cold	It2: Imported food safety risks		
PB5: Risks to people, communities & buildings from flooding	It3: Long-term changes in global food production		
PB9: Risks to health and social care delivery from extreme weather	It5: Risks to the UK from international violent conflict		
Bu1: Risks to business sites from flooding	It6: Risks to international law and governance		
It1: Weather-related shocks to global food production and trade			
It4: Risks from climate-related international human displacement			

KEY TO CHAPTERS:

- Chapter 3: Natural environment and natural assets
- Chapter 4: Infrastructure
- Chapter 5: People and the built environment
- Chapter 6: Business and industry
- Chapter 7: International dimensions

Note: Individual risks and opportunities are presented in the order they are discussed in the chapters (not in priority order).

www.theccc.org.uk/uk-climate-change-risk-assessment-2017

Figure SR.2: Urgency of risks and opportunities identified and discussed in the vidence Report

MORE ACTION NEEDED	RESEARCH PRIORITY	SUSTAIN CURRENT ACTION	WATCHING BRIEF
from drought and low river flows	Bu2: Risks to business from loss of coastal locations & infrastructure		
PB1: Risks to public health and wellbeing from high temperatures	Bu5: Employee productivity impacts in heatwaves and from severe weather infrastructure disruption		
PB4: Potential benefits to health & wellbeing from reduced cold	It2: Imported food safety risks		
PB5: Risks to people, communities & buildings from flooding	It3: Long-term changes in global food production		
PB9: Risks to health and social care delivery from extreme weather	It5: Risks to the UK from international violent conflict		
Bu1: Risks to business sites from flooding	It6: Risks to international law and governance		
It1: Weather-related shocks to global food production and trade			
It4: Risks from climate-related international human displacement			

KEY TO CHAPTERS:

- Chapter 3: Natural environment and natural assets
- Chapter 4: Infrastructure
- Chapter 5: People and the built environment
- Chapter 6: Business and industry
- Chapter 7: International dimensions

Source: ASC judgement in discussion with lead contributors, based on the evidence of magnitude, current and potential adaptation, and benefits of further action in the next five years, presented within the Evidence Report chapters.

Notes: Individual risks and opportunities are presented in the order they are discussed in the chapters (not in priority order). The urgency categories are defined as follows:

- **More action needed:** New, stronger or different government policies or implementation activities– over and above those already planned – are needed to reduce long-term vulnerability to climate change.
- **Research priority:** Research is needed to fill significant evidence gaps or reduce the uncertainty in the current level of understanding in order to assess the need for additional action.
- **Sustain current action:** Current or planned levels of activity are appropriate, but continued implementation of these policies or plans is needed to ensure that the risk continues to be managed in the future. This includes any existing plans to increase or change the current level of activity.
- **Watching brief:** The evidence in these areas should be kept under review, with long-term monitoring of risk levels and adaptation activity so that further action can be taken if necessary.

See Chapter 2 of the Evidence Report for more details of the urgency scoring methodology used.

Vulnerabilities

Figure SR.A1: Climate change risks and opportunities for the natural environment

Natural Assets

3.2: Terrestrial

Ne1: Risks to species and habitats due to inability to respond to changing climatic conditions

Ne2: Opportunities from new species colonisations

3.3: Soils and Land

Ne3: Risks and opportunities from changes in agricultural and forestry productivity and land suitability

Ne 4: Risks to soils from seasonal aridity and wetness

Ne8: Risks of land management practices exacerbating flood risk

Ne10: Risks to agriculture, forestry, wildlife and heritage from change in frequency and/or magnitude of extreme weather and wildfire events

3.4: Freshwater

Ne6: Risks to agriculture and wildlife from water scarcity and flooding

Ne7: Risks to freshwater species from higher water temperatures

3.5: Coasts

Ne11: Risks to aquifers, agricultural land and habitats from salt water intrusion

Ne12: Risks to habitats and heritage in the coastal zone from sea-level rise; and loss of natural flood protection

3.6: Marine

Ne13: Risks to, and opportunities for, marine species, fisheries and marine heritage from ocean acidification and higher water temperatures

3.7: Cross-Cutting Issues

3.7.1: Pests and Diseases

Ne9: Risks to agriculture, forestry, landscapes and wildlife from pests, pathogens and invasive species

3.7.2: Natural Carbon Stores

Ne5: Risks to natural carbon stores and carbon sequestration

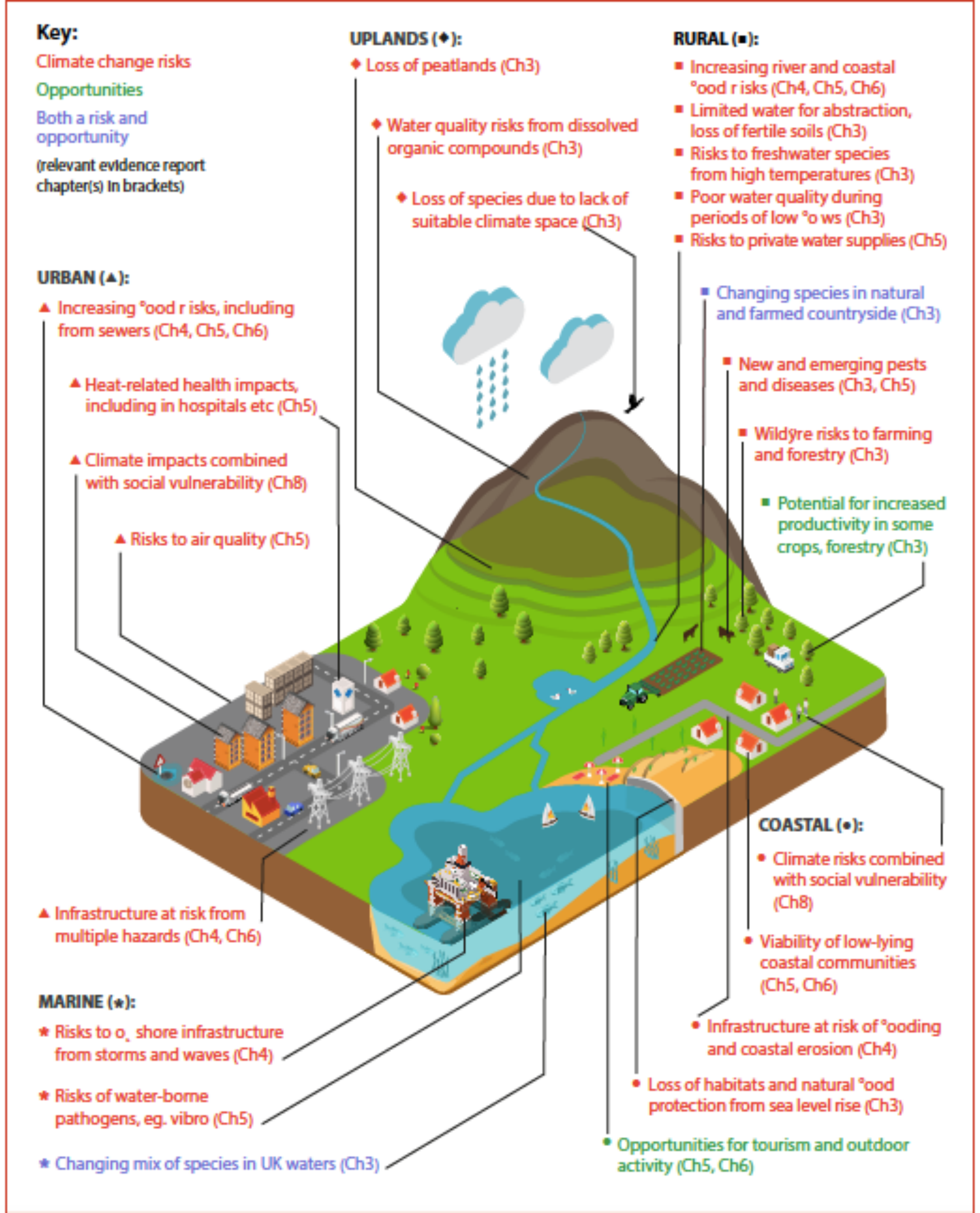
3.7.3: Landscape and Sense of Place

Ne14: Risks and opportunities from changes in landscape character

Source: CCRA2 Evidence Report, Chapter 3.
Notes: Numbers denote the sections of Chapter 3 discussing the issues presented.

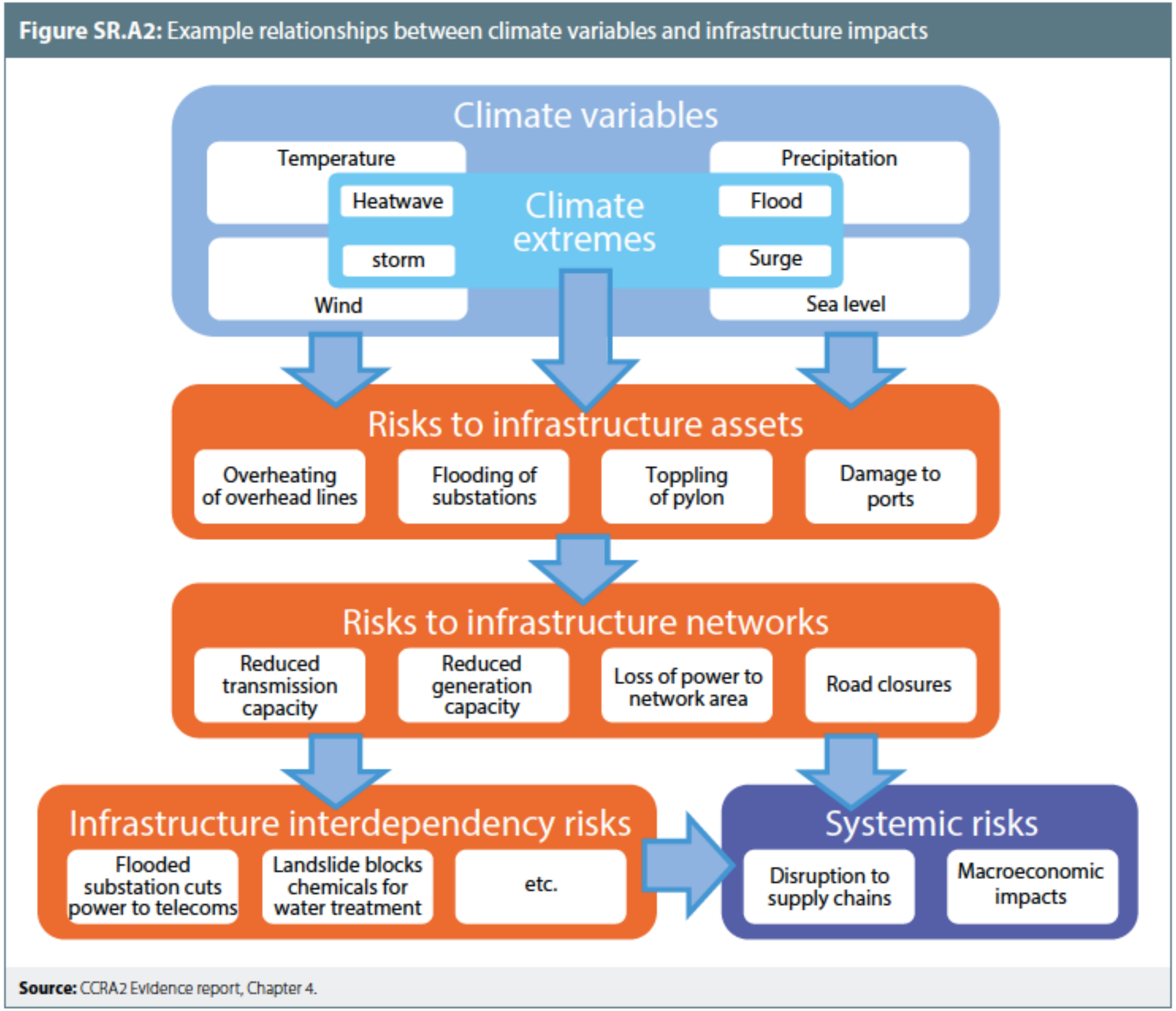
Vulnerabilities

Figure SR.10: UK climate change risks and opportunities for different types of area



Source: ASC synthesis of the Evidence Report chapters.
Notes: The risks presented are not exhaustive and will not be confined to the types of area shown. See chapters of the Evidence Report for more details.

Vulnerabilities



Vulnerabilities

Figure SR.1: Top six areas of inter-related climate change risks for the United Kingdom

Source: ASC synthesis of the main areas of risk and opportunity within the chapters of the Evidence Report.
Notes: Future magnitude is based on a combination of climate change and other drivers of risk (e.g. demographic change), taking account of how current adaptation policies and plans across the UK are likely to reduce risks.

Vulnerabilities

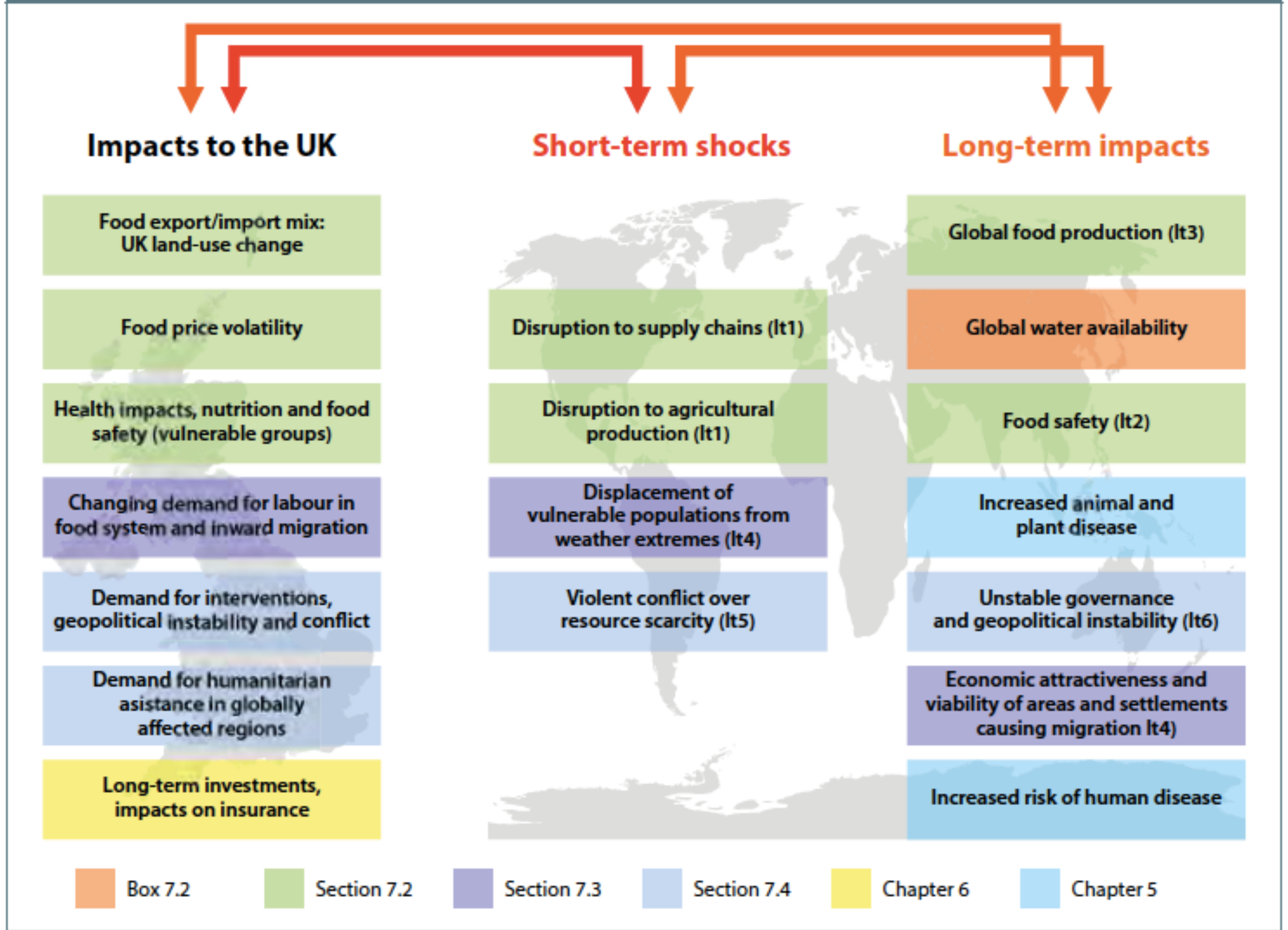
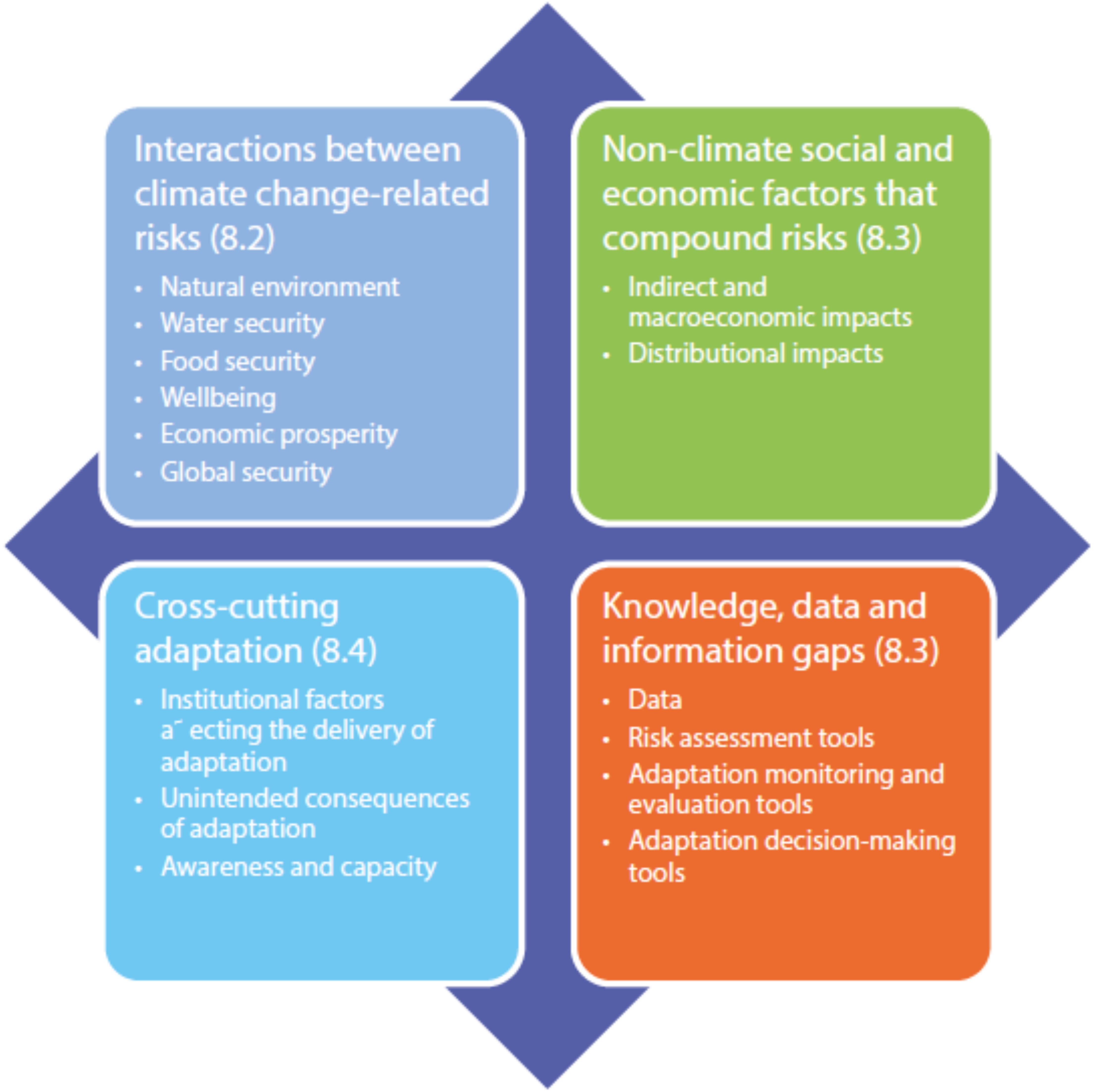


Figure SR.A5: International dimensions of climate change risk

Source: CCRA2 Evidence Report, Chapter 7.

Vulnerabilities

Figure SR.A6: Cross-cutting issues affecting climate change risks



Source: CCRA2 Evidence Report, Chapter 8.

Table 1 Vulnerability to and impacts of LSLR

Hazard or impact	*Direct health impacts*	*Health infrastructure*
Catastrophic coastal flooding	Deaths through drowning and other causes, injuries, infectious diseases (respiratory, intestinal, skin), mental health disorders	Health services interruption, availability of health staff, transportation disruption, energy and other supplies
Flood-induced pollution	Infectious diseases, allergies	Long-lasting degradation of health service infrastructure
Reduced water quality and reduced access to potable water due to salinification and/or pollution	Diarrheal diseases (giardia, cholera), hepatitis, other water borne diseases	Reduced water supply for health services
Impairment of food quality (through pollution of farmland and fisheries) and reduction of food supply (e.g., loss of farmland and decreasing productivity of fisheries)	Malnutrition; shellfish poisoning, marine bacteria proliferation	Food safety
Change in transmission intensity, distribution of vector-borne disease, abundance of vectors	Changes in malaria and other mosquito-borne infectious diseases	
Population displacements, degradation of livelihoods	Less well defined; can include increased social conflicts; increased crime rate; prostitution to replace lost income	General stress on health services because of rapid changes in demands

Modified from Nicholls, R. J., P. P. Wong, V. R. Burkett, J. O. Codignotto, J. E. Hay, R. F. McLean, S. Ragoonaden, and C. D. Woodroffe, 2007b: Coastal systems and low-lying areas. *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, M. L. Parry, O. F. Canziani, J. P. Palutikof, P. J. van der Linden, and C. Hanson, Eds., Cambridge University Press, Cambridge, UK, 315–356.

Executive summary

Climate change currently contributes to the global burden of disease and premature deaths (very high confidence).
Human beings are exposed to climate change through changing weather patterns (temperature, precipitation, sea-level rise and more frequent extreme events) and indirectly through changes in water, air and food quality and changes in ecosystems, agriculture, industry and settlements and the economy. At this early stage the effects are small but are projected to progressively increase in all countries and regions. [8.4.1]

Emerging evidence of climate change effects on human health shows that climate change has:

- altered the distribution of some infectious disease vectors (medium confidence) [8.2.8];
- altered the seasonal distribution of some allergenic pollen species (high confidence) [8.2.7];
- increased heatwave-related deaths (medium confidence) [8.2.1].

Projected trends in climate-change-related exposures of importance to human health will:

- increase malnutrition and consequent disorders, including those relating to child growth and development (high confidence) [8.2.3, 8.4.1];
- increase the number of people suffering from death, disease and injury from heatwaves, floods, storms, fires and droughts (high confidence) [8.2.2, 8.4.1];
- continue to change the range of some infectious disease vectors (high confidence) [8.2, 8.4];
- have mixed effects on malaria; in some places the geographical range will contract, elsewhere the geographical range will expand and the transmission season may be changed (very high confidence) [8.4.1.2];
- increase the burden of diarrhoeal diseases (medium confidence) [8.2, 8.4];
- increase cardio-respiratory morbidity and mortality associated with ground-level ozone (high confidence) [8.2.6, 8.4.1.4];
- increase the number of people at risk of dengue (low confidence) [8.2.8, 8.4.1];
- bring some benefits to health, including fewer deaths from cold, although it is expected that these will be outweighed by the negative effects of rising temperatures worldwide, especially in developing countries (high confidence) [8.2.1, 8.4.1].

Adaptive capacity needs to be improved everywhere; impacts of recent hurricanes and heatwaves show that even high-income countries are not well prepared to cope with extreme weather events (high confidence). [8.2.1, 8.2.2]

Adverse health impacts will be greatest in low-income countries. Those at greater risk include, in all countries, the urban poor, the elderly and children, traditional societies, subsistence farmers, and coastal populations (high confidence). [8.1.1, 8.4.2, 8.6.1.3, 8.7]

Economic development is an important component of adaptation, but on its own will not insulate the world's population from disease and injury due to climate change (very high confidence).
Critically important will be the manner in which economic growth occurs, the distribution of the benefits of growth, and factors that directly shape the health of populations, such as education, health care, and public-health infrastructure. [8.3.2]

Table 1 Vulnerability to ...

Hazard or impact	...*tructure*
Catastrophic coastal flooding...	...es interruption, availability of ...ff, transportation disruption, ...d other supplies
Flood-induced pollution	... degradation of health service ...ture
Reduced water quality and r... to potable water due to sa... and/or pollution	...ter supply for health services
Impairment of food quality (... of farmland and fisheries) ... food supply (e.g., loss of ... decreasing productivity of ...	
Change in transmission inter... vector-borne disease, abu...	
Population displacements, d... livelihoods	...ss on health services because of ...nges in demands

Modified from Nicholls, R. J., P. ... 2007b: Coastal systems and low-lying areas. *Climate Change 2007: Impa... Governmental Panel on Climate Change*, M. L. Parry, O. F. Canziani, J. P. ... 5–356.

Risk Distribution

Risk Distribution

- There are always risks
- Risk distribution is uneven in space

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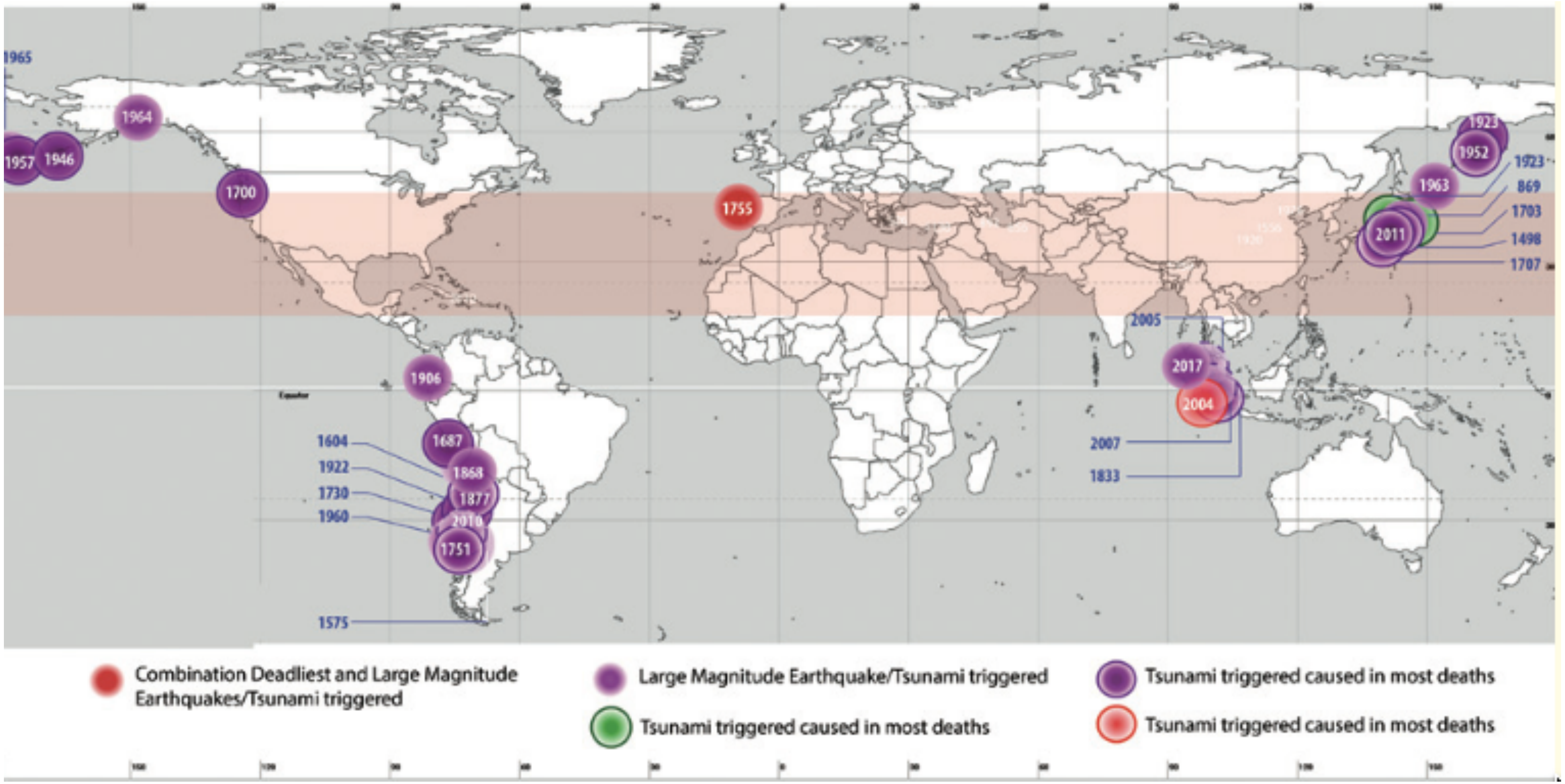

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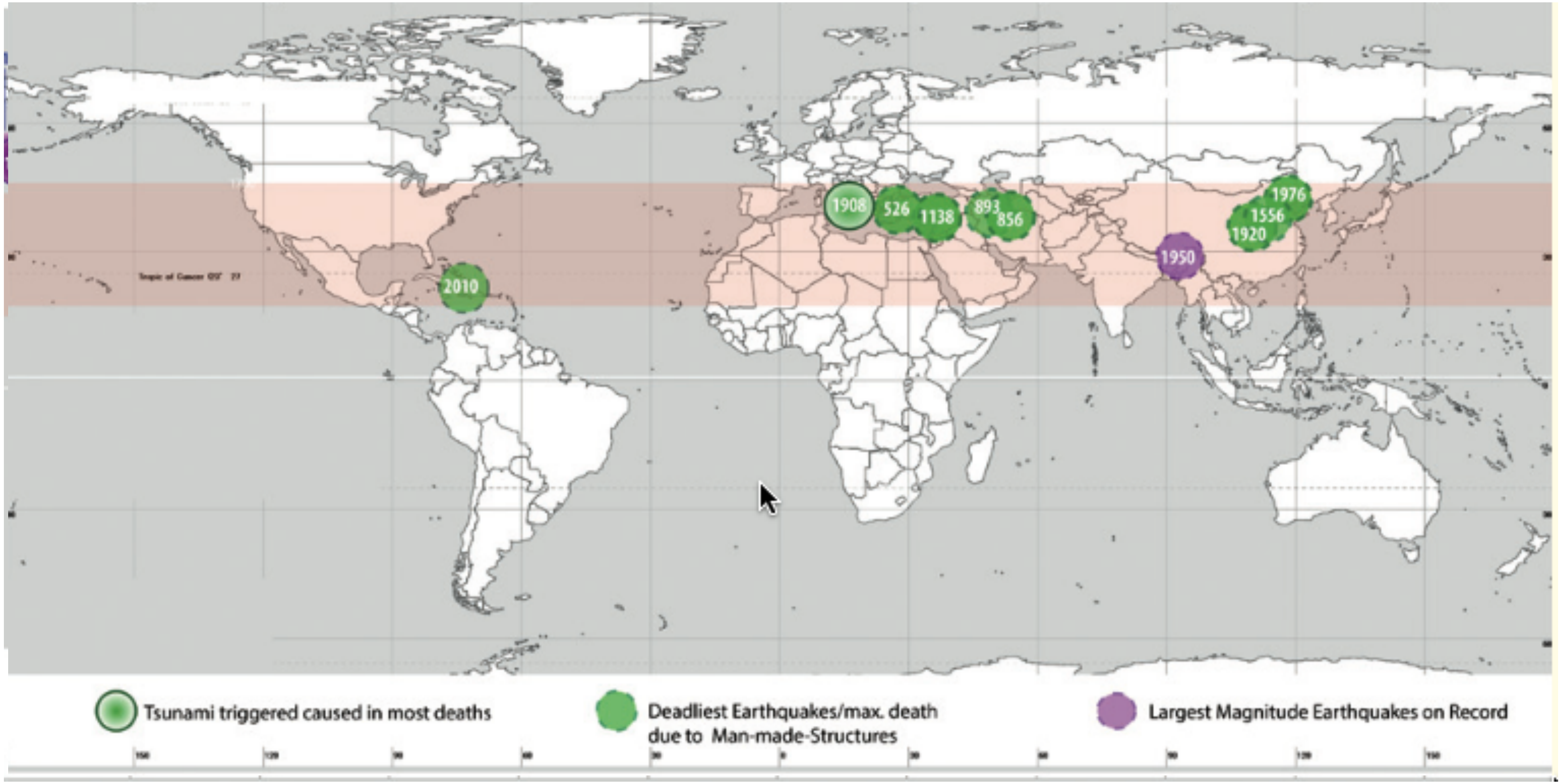

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Inequality in Climate and Global Change Impacts

Risk Distribution

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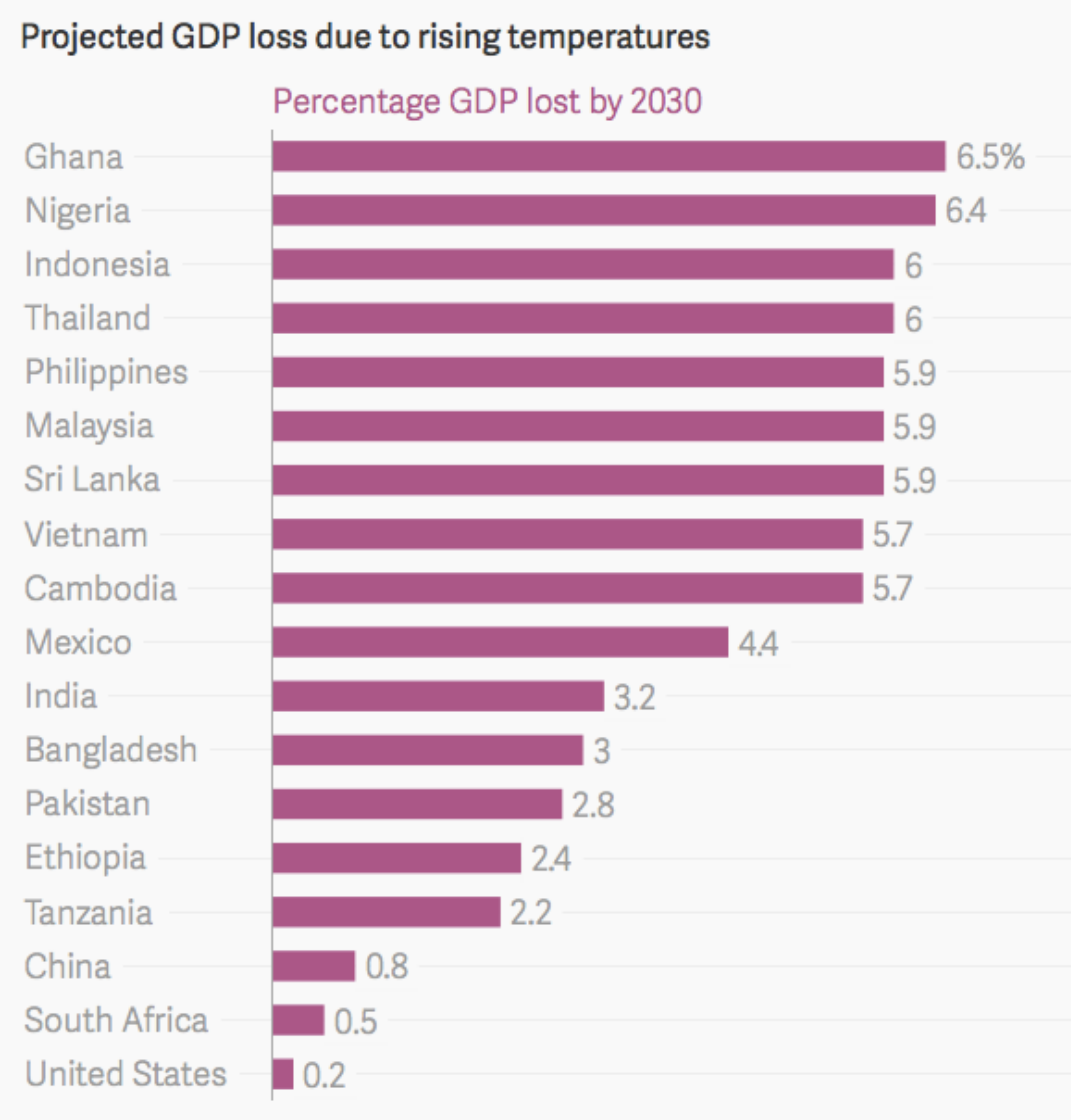

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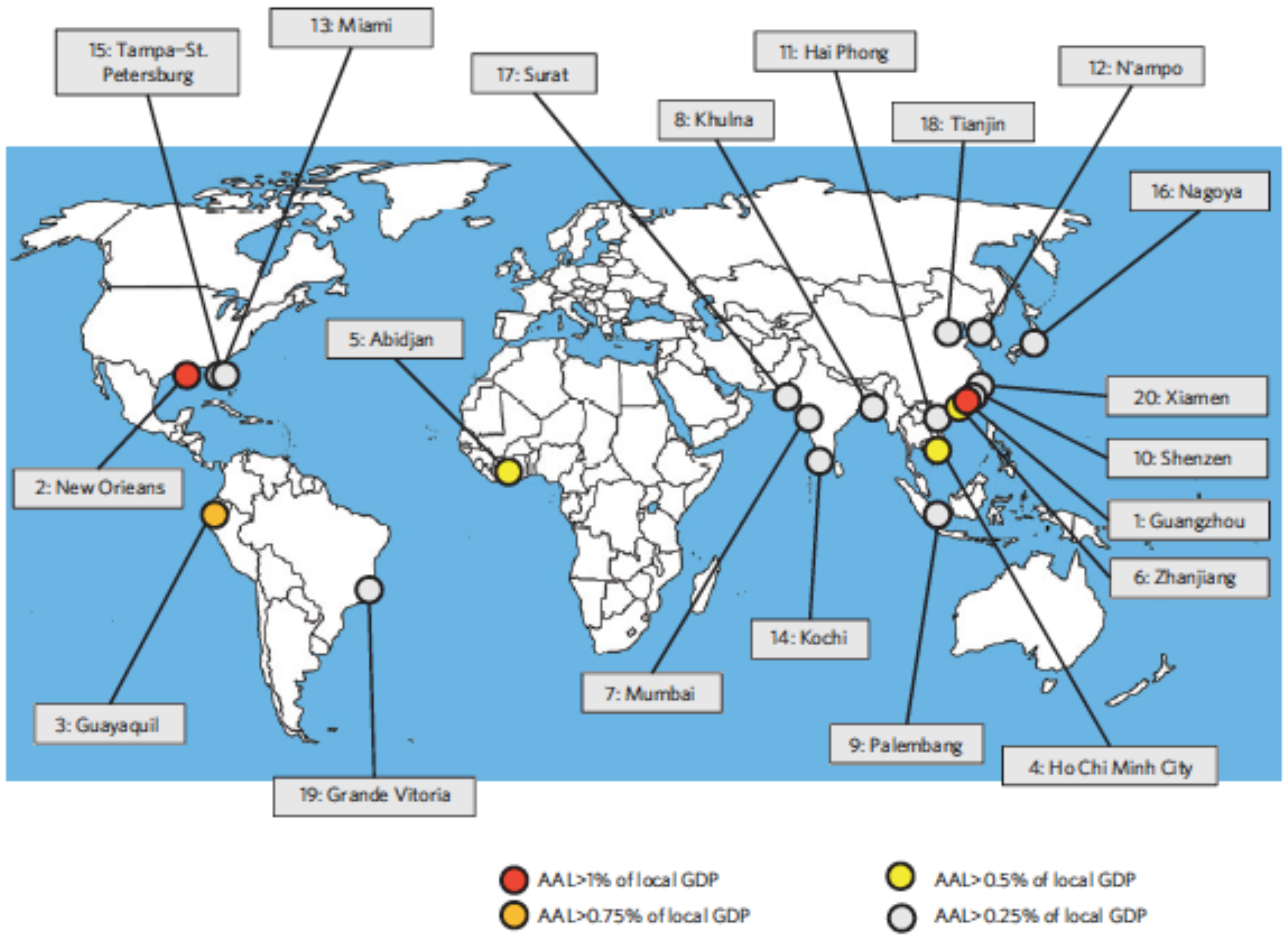

LETTERS NATURE CLIMATE CHANGE DOI: 10.1038/NCLIMATE1979

Table 1 | City ranking by risk (AAL) and relative risk (AAL in percentage of GDP) for 2005.

	Ranking by AAL (US$ million)					Ranking by relative AAL (percentage of city GDP)			
	Urban agglomeration	100 year exposure	AAL, with protection (US$ million)	AAL, with protection (percentage of GDP)		Urban agglomeration	100 year exposure	AAL, with protection (US$ million)	AAL, with protection (percentage of GDP)
1	Guangzhou	38,508	687	1.32%	1	Guangzhou	38,508	687	1.32%
2	Miami	366,421	672	0.30%	2	New Orleans	143,963	507	1.21%
3	New York—Newark	236,530	628	0.08%	3	Guayaquil	3,687	98	0.95%
4	New Orleans	143,963	507	1.21%	4	Ho Chi Minh City	18,708	104	0.74%
5	Mumbai	23,188	284	0.47%	5	Abidjan	1,786	38	0.72%
6	Nagoya	77,988	260	0.26%	6	Zhanjiang	2,780	46	0.50%
7	Tampa—St. Petersburg	49,593	244	0.26%	7	Mumbai	23,188	284	0.47%
8	Boston	55,445	237	0.13%	8	Khulna	2,073	13	0.43%
9	Shenzen	11,338	169	0.38%	9	Palembang	1,161	27	0.39%
10	Osaka—Kobe	149,935	120	0.03%	10	Shenzen	11,338	169	0.38%
11	Vancouver	33,456	107	0.14%	11	Hai Phòng	6,348	19	0.37%
12	Tianjin	11,408	104	0.24%	12	N'ampo	507	6	0.31%
13	Ho Chi Minh City	18,708	104	0.74%	13	Miami	366,421	672	0.30%
14	Kolkata	14,769	99	0.21%	14	Kochi	855	14	0.29%
15	Guayaquil	3,687	98	0.95%	15	Tampa—St. Petersburg	49,593	244	0.26%
16	Philadelphia	22,132	89	0.04%	16	Nagoya	77,988	260	0.26%
17	Virginia Beach	61,507	89	0.15%	17	Surat	3,288	30	0.25%
18	Fukuoka—Kitakyushu	39,096	82	0.09%	18	Tianjin	11,408	104	0.24%
19	Baltimore	14,042	76	0.08%	19	Grande_Vitória	6,738	32	0.23%
20	Jakarta	4,256	73	0.14%	20	Xiamen	4,486	33	0.22%

A comparison with a ranking by exposure is proposed in the Supplementary Information.

Risk Distribution

- There are always risks
- Risk distribution is uneven in space

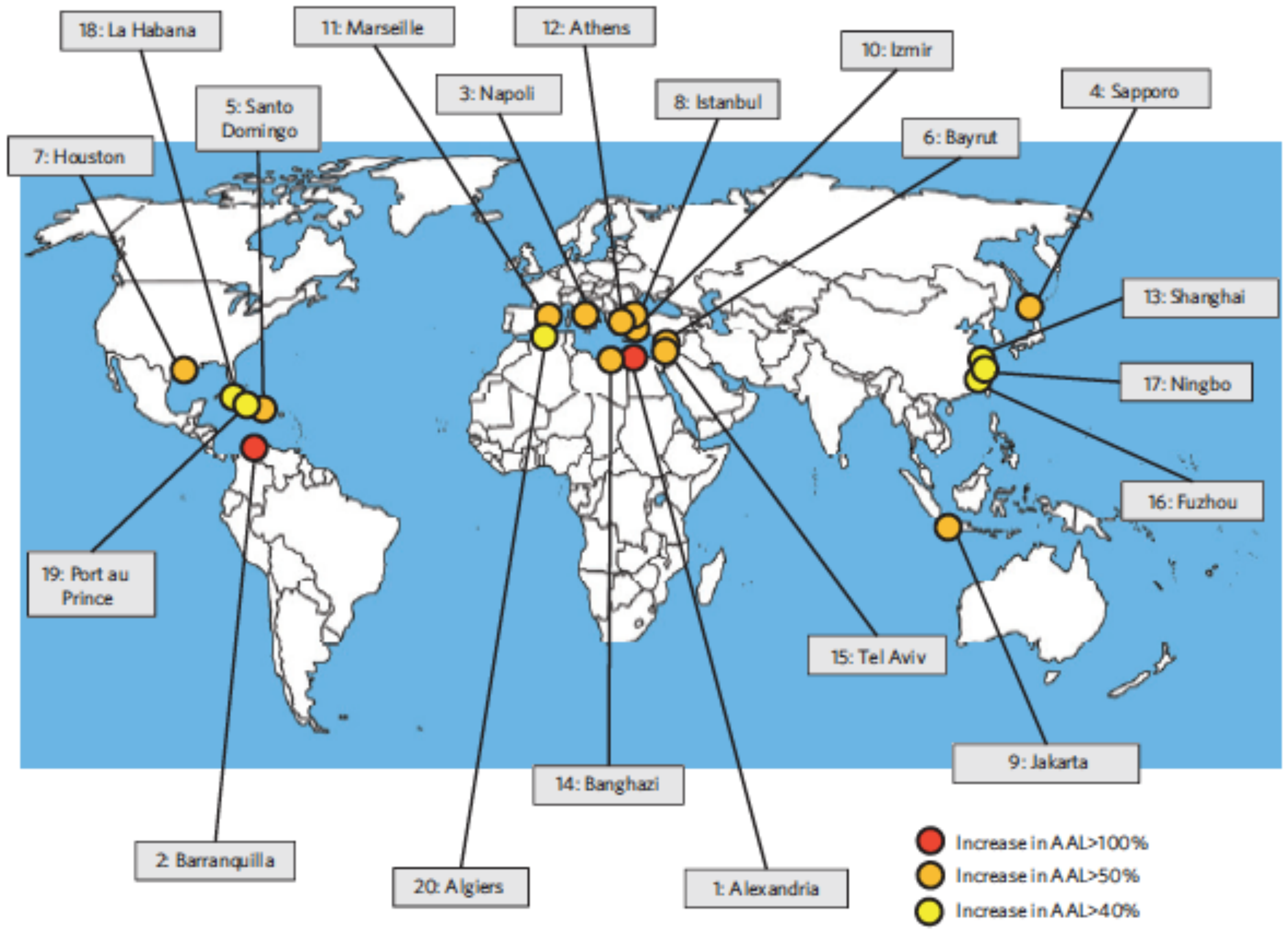

Figure 2 | The 20 cities where AAL increase most (in relative terms in 2050 compared with 2005) in the case of optimistic sea-level rise, if adaptation only maintains present defence standards or flood probability (PD). More information in Supplementary Table S7.

Table 2 | The 20 cities with the highest loss in 2050, assuming scenario SLR-1 and adaptation option that maintains flood probability (option PD).

	Scenarios with socio-economic change alone (SEC)		Scenarios with socio-economic change, subsidence, sea-level rise and adaptation to maintain flood probability (scenarios SLR-1, and adaptation option PD)		
Urban agglomeration	AAL (US$ million)	AAL (percentage of city GDP)	AAL (US$ million)	Increase in AAL compared with 2005 (%)	AAL (percentage of city GDP)
Guangzhou (S)	11,928	1.32%	13,200	11%	1.46%
Mumbai	6,109	0.47%	6,414	5%	0.49%
Kolkata (S)	2,704	0.21%	3,350	24%	0.26%
Guayaquil (S)	2,813	0.95%	3,189	13%	1.08%
Shenzen	2,929	0.38%	3,136	7%	0.40%
Miami	2,099	0.30%	2,549	21%	0.36%
Tianjin (S)	1,810	0.24%	2,276	26%	0.30%
New York—Newark	1,960	0.08%	2,056	5%	0.08%
Ho Chi Minh City (S)	1,743	0.74%	1,953	12%	0.83%
New Orleans (S)	1,583	1.21%	1,864	18%	1.42%
Jakarta (S)	1,139	0.14%	1,750	54%	0.22%
Abidjan	826	0.72%	1,023	24%	0.89%
Chennai (Madras)	825	0.12%	939	14%	0.14%
Surat	905	0.25%	928	3%	0.26%
Zhanjiang (S)	806	0.50%	891	11%	0.55%
Tampa—St. Petersburg	763	0.26%	859	13%	0.29%
Boston	741	0.13%	793	7%	0.14%
Bangkok (S)	596	0.07%	734	23%	0.09%
Xiamen (S)	572	0.22%	729	27%	0.29%
Nagoya (S)	564	0.26%	644	14%	0.30%

'S' indicates that the city is prone to significant subsidence. Most of these cities are located in deltaic regions, where subsidence influences local sea level in 2050.

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Attack of the extreme floods

As the oceans rise, researchers aim to forecast where severe storms will trigger the worst flooding.

Alexandra Witze

THE COMING FLOODS

Mean sea levels are rising around the globe, which is affecting the rate of floods in various locations. By 2050, some places (darker red dots) can expect to see what is currently considered a 100-year flood event recur as often as every one or five years on average. In other areas, today's 100-year events will not become more common or may even become rarer (light-blue dots), such as along Scandinavian coasts where the land is rising relative to the sea. Low-lying Pacific islands are among the most vulnerable to increased coastal flooding.

Estimated frequency by 2050 of today's 100-year floods (years)
● 1–2 ● 2–5 ● 5–10 ● 10–20 ● 20–50 ● 50–100 ● 100–10,000

T. Wahl *et al. Nature Commun.* http://dx.doi.org/10.1038/ncomms16075 (2017).

Risk Distribution

- There are always risks
- Risk distribution is uneven in space
- Risk distribution is uneven in time

Inequality in Climate and Global Change Impacts

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Example:
Since 1970, the number of people exposed to floods and tropical cyclones has doubled.

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People in a waterside house raised on stilts in a slum in Manila. © Robin Hammond / Panos

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Resilience and the inequality of risk

We need a new approach to risk and poverty reduction. Major external risks, such as climate change and food price volatility, are increasing faster than attempts to reduce them. Many risks are dumped on poor people, and women face an overwhelming burden. In many places of recurrent crises, the response of governments and the international aid sector is not good enough. A new focus on building resilience offers real promise to allow the poorest women and men to thrive despite shocks, stresses, and uncertainty – but only if risk is more equally shared globally and across societies. This will require a major shift in development work, which for too long has avoided dealing with risk. More fundamentally, it will require challenging the inequality that exposes poor people to far more risk than the rich.

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None of the consequences of these shocks and stresses are equal. Poor people and poor countries suffer immeasurably more than others. In relative terms, the financial impact of disasters is far higher in developing countries. For example, South Asia suffers flood losses that are 15 times greater, as a percentage of GDP, than OECD countries.
Those who are hit hardest are always the poorest, because they do not have access to welfare or social protection schemes, insurance, or „something in the kitty" to help them withstand an emergency.

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- Risk can be socialized through insurance

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97% of people on low incomes have no insurance cover, and 90% of workers in least developed countries have no social security

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