Resilience: Moving Forward from a Metaphor

José Palma-Oliveira[i*] and Benjamin D. Trump[i]

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[*]Corresponding author: jpalma-oliveira@psicologia.ulisboa.pt

Resilience and complex systems

Resilience remains a field of tremendous potential to improve the management and sustainability of ecological and environmental systems – particularly in the manner by which humans engage within them. Many papers have argued that as a property of a system, resilience focuses upon 'bouncing back' to an initial steady state. Further, others operate under the assumption that resilience is a normatively positive characteristic to possess and tends to produce desirable outcomes. While in many cases this is somewhat true, in others it raises the threat of misdiagnosis of systemic threats as well as mismanagement of at-risk ecological systems.

In volume 1 of IRGC's Resource Guide on Resilience (Palma-Oliveira & Trump, 2016), we argued that the methodological promise of resilience is being overshadowed by its use as a metaphor for sustaining a system's ideal state. In this volume, we argue that an improved application and scientifically-grounded understanding of ecological resilience can be formulated by an improved understanding of when such systems reach tipping or transition points. Scholarly literature such as Walker et al. (2004), Folke et al. (2010), Gallopin (2006), and Dai et al. (2012) offer scientifically-grounded approaches to model and assess ecosystem and environmental resilience as a measure of whether the current environmental system is stable, or whether it is nearing a tipping or transformation point. We apply the logic of such literature to emerging environmental and ecological concerns such as ocean pollution and climate change and describe how normatively positive or negative influences have the potential to shift an environmental system into a differing stable state.

Risk, resilience, and complex adaptive systems

Neither risk nor resilience are new disciplines. From an environmental perspective, the Ancient Egyptians regularly reviewed risk-based predictions for the annual inundation of the Nile River – excessive inundation could flood and destroy fields and rot crops, while too little flooding would limit grain production and threaten starvation for the land. Likewise, resilience has been used as a term to define systemic capacity to overcome disruption for at least two thousand years, such as with resiliency in Roman Republican rule despite political infighting, economic woes, or natural disasters (Alexander, 2013).

[i] University of Lisbon, Portugal

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More recently, the risk/resilience divide has become clearer and more bound to methodological practice (Linkov & Trump, 2019). On one hand, risk analysis in the environmental practice has centred upon reviewing the potential hazards to a component of a system, mapping the vulnerabilities of the system component to the hazard, and the ultimate consequences should that vulnerability be exploited. This has allowed eminent scientists, government agencies, NGOs, and scholars to better understand various environmental threats such as with the continual use of dichlorodiphenyltrichloroethane (DDT) chemical sprays as insecticide to human or environmental health, or the impact of chlorofluorocarbon (CFC) use upon the ozone layer. Decades of risk-based research have demonstrated that when we can clearly identify and unpack a specific threat (or 'risk object') to a specific target within the environment (or 'object at risk'), we can often calculate the relative riskiness that such a threat has and make specific determinations regarding its safe use and good governance (Boholm & Corvellec, 2011).

However, when the risk object is poorly understood, or the object at risk is incredibly complex and consists of many nested sub-systems, traditional risk analysis does not generate the same level of quantitative rigor that decision makers normally require. Further, there is often a lack of consensus amongst the different groups regarding whether something is a risk object or an object at risk (Palma-Oliveira et al., 2018). This is reflected in many emerging challenges today, ranging from global climate change to the sudden spread of harmful algal blooms generated by certain species of phytoplankton and dinoflagellates (known colloquially as 'red tide'), where complex systems encounter a sudden yet poorly predicted shock to their equilibria. Without reliable risk forecasting and signal detection, as well as data to unpack the hazard, exposure, and effects assessment necessary to conduct risk analysis, systemic shocks to complex environmental systems are generally difficult to predict or solve with a risk-based approach.

Resilience affords greater clarity over such threats (particularly systemic threats) by focusing upon the inherent structure of the system, its core characteristics, and the relationship that various sub-systems have with one another to generate an ecosystem's baseline state of health (IRGC, 2018). Walker et al. (2004) define ecosystem equilibria as a characteristic of "basins of attraction", where the components and characteristics of a system drive it towards a baseline state of health and performance. For example, the Pacific Ocean is a huge and complex ecosystem with a tremendous diversity of flora and fauna whose roles in complex food webs have been reinforced by millions of years of evolution and adaptivity; a localized oil spill may damage small points of ecosystem health but is unlikely to dramatically and permanently shift the species dynamics and food webs which currently prevail across most of the Ocean. However, through constant exposure to trillions of microplastics (i.e., the Pacific Trash Vortex) or continuous chemical and radiological contaminants (i.e. bleaching of the Great Barrier Reef, radiological runoff from the Fukushima Daiichi Nuclear Power Plant), system equilibria can be jolted in a manner that favours a differing basin of attraction. Unfortunately, we are moving in that direction already, where huge regions of oxygen-depletion in the Pacific Ocean are contributing to 'dead zones' where virtually no marine life can survive.

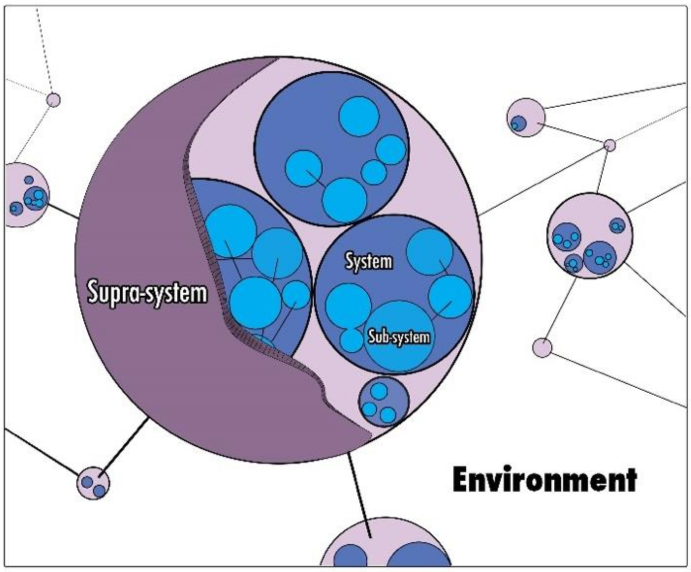

Figure 1: Illustration of a complex interconnected environmental system (Linkov & Trump, in press)

Both the initial Pacific Ocean baseline state of health (a larger, global system), as well as these dead zones (sub-system within the Pacific Ocean global system), are fundamentally resilient systems that are defined by basins of attraction which possess characteristics that reinforce the status quo in the absence of a shock or disruption. On one hand, a biologically rich and diverse Pacific biological system has recovered from a tremendous array of disruptions over the past century, or adapted system processes in a way that address incoming challenges such as with large-scale commercial fishing. However, continuous overfishing along with chemical and radiological runoff are disrupting the Pacific ecosystem enough to potentially transition it towards a new and less biologically complex basin of attraction. This will be further discussed in the last section.

More than just a metaphor, ecosystem resilience describes the intensity of a given ecological basin of attraction to preserve the baseline state of health and activity within a given area, whether that state is optimum, desirable or not. It could be normatively positive (i.e., a complex and biodiverse Pacific Ocean) or negative (i.e., a Pacific Ocean comprised of huge dead zones and limited biodiversity). Methodologically, such basins of attraction are comprised of complex interconnected and adaptive systems that are constantly under stress, yet only shift to a new equilibrium if a tipping point has been breached and the system is trending towards a new basin. More than just system recovery and adaptation, ecosystem resilience is a property of natural selection and organism interaction within their broader environment in a manner that produces some sustainable end-state. Such resilience-based approaches can help us understand when and how certain ecosystems might shift from one steady-state to another (Linkov et al., 2018), as well as define the biological and ecological drivers which cause an ecosystem to arrive at a steady equilibrium altogether.

In the modern age, there is no socioecological system that is not influenced by human behaviour or activity. Increasingly, many research organizations find that human activity is directly or indirectly pushing environmental and ecological systems from an initial condition of high biodiversity and systemic complexity, towards more simple, less diverse, and less hospitable climates and food webs. Some human-derived disruptions are relatively abrupt (e.g., industrial logging in tropical rainforests) or more gradual in effect (e.g., ocean pollution), yet both tend to drive such environmental and ecological systems towards a tipping point that limits the potential for diverse environmental life. Such a system is resilient yet normatively unfavourable, where significant energy and resources would have to be dedicated towards returning an at-risk environment to its original basin of attraction.

Risk, resilience, and the nagging worry of brittleness

It is critically important for practitioners to acknowledge, in spite of the benefits of such a governing strategy, the drawbacks of a resilience-based approach for ecosystem health. While facilitating the expeditious recovery of normatively positive systems from disruption is a helpful goal for ecosystem health, it is essential to acknowledge how developing ecological and biological properties resistant to transition or transformation can contribute to inherent brittleness in certain areas of the ecosystem. In essence, resilience-based drawbacks arrive in two areas: an ecosystem that is believed to be resilient and thus can withstand and recover from virtually any disruption (and thereby taking few steps to protect against such disruptions), or the simultaneous development of areas of systemic brittleness while fostering resilience in others.

We have already seen countless examples of the former. Widespread overfishing, dumping of waste, or atmospheric pollution have been rampant within the 20th and 21st Centuries despite evidence that related ecosystems were more fragile, unsustainable and not resilient, and many international agreements to reduce such damage. Many reference a belief in the inherent resilience of the system as a root cause of the acceptability of such behaviour, contributing to classic tragedies of the commons and anticommons. A belief in ecosystem resilience reinforces commons-related problems worldwide by enabling feedback mechanisms and social traps which cause individuals to behave in socially and globally harmful manners.

For the latter, developing resilient properties in some areas of complex ecosystems can generate brittleness in others. For example, some scholars have discussed the use of gene drives to improve the resistance of endangered species of coral to bleaching as well as to improve its ability to survive and reproduce in various other hazardous environmental conditions (notably, the Great Barrier Reef). Such genetic changes would foster increased capacity for at-risk coral to resist bleaching (vis-à-vis a 'risk-based approach') as well as potentially enable various species of coral to quickly recover from other possible disruptions in the future such as ocean acidification (a 'resilience-based approach' which emphasizes quick recovery and adaptation to future potential threats). However, the use of a gene drive for coral conservation and resiliency might have unintended side effects, such as threats to biodiversity via horizontal gene transfer, or potentially through excessive growth of such coral reefs in a manner that outstrips local food supplies. This is not to rule out such a technological solution to a complex ecosystem concern, but a necessary governance challenge of any effort to develop ecosystem resiliency must consider the unintended consequences of causing one species of flora or fauna to outperform or proliferate in a manner outside of the current ecosystem equilibrium. Further, one must acknowledge how an intervention to a specific sub-system (e.g., the Great Barrier Reef) might trigger secondary effects to nested sub-systems (other marine life) or the larger global system (the South Pacific Ocean).

Resilience means adaptation: Basins of attraction and transition points

Shocks and stresses are frequently discussed in scholarly literature as disruption events for complex systems, yet rarely acknowledge that such disruptions can contribute to (a) a reorganization of the same general system, or (b) contribute to a collapse of the original system, and foster the creation of a new system and basin of attraction altogether. For the former, some disruptions can generate substantial change in some areas yet preserve the overall system's functions and characteristics. For example, many forest fires can destroy large forests, yet in the aftermath of such fires an environmental system can use the nutrients from the burned flora to foster new tree growth. Elements or subcomponents of the forest system may change over time in response to such fires, yet the baseline characteristics of that system are often able to return to prominence.

Other disruptions generate collapses in the status quo system altogether. If a disruption is particularly consequential and removes the preconditions by which the system can recover and reorganize in a manner similar to the initial system structure, such a disruption can instead cause the destruction of the original system in favour of one that is entirely different in its characteristics and baseline state of health. For example, the widespread dumping and persistence of plastic in the Pacific Ocean is dramatically altering the capacity of ocean regions to sustain marine line, and limit localized ecosystems to tolerate only those organisms which can persist with minimal sunlight or oxygen.

All systems are dynamically interconnected and are continually interacting and adapting within and across one another to best compete and operate within a given system paradigm. This idea, known academically as panarchy, is particularly salient when describing environmental and ecological systems as well as the foundational theories of evolution and natural selection. While there are many drivers which influence and shift behaviour within one or more components of a system, we identify three key influences of ecosystem adaptation and transition, including (a) solar and climatological influences, (b) bio-geological forces, and (c) socioeconomic human activity.

More simply put, the interrelationships between humans, local ecosystems, and global climate and solar activity collectively influence the (in)stability of environmental systems, as well as how certain disruptions may or may not disrupt the current basin of attraction. Typically, bottom-up disruptions at localized levels rarely can trigger greater systemic transformations, yet they can shift or alter the characteristics of ecosystem health. Likewise, disruptions at the global level of a system (e.g., solar storms, ozone depletion, etc.) can trigger rapid and disastrous systemic risks that can fundamentally change the nature of life on Earth. The critical question of how such systems are governed depends upon where and how a potential disruption may occur – on a local level that may be resolved via limited or directed engagement such as with environmental remediation of a contaminated site, or on a global scale that requires the coordination of many actors to reduce the threat of global catastrophe, such as with the effect of CFCs upon the global ozone layer.

The purpose of developing a normatively positive, resilient system is to instil within it the capabilities to incorporate new information within the environment, and adapt accordingly to such stimuli in order to adapt to all the types of changes and tipping points described above. Reviewing Walker et al. (2004), ecosystem resilience is defined by its tipping points, or transitionary periods, where a shock or stress will push a system away from one basin of attraction and into another. The critical question for policy- and decision-makers pertinent to environmental policy centers upon how can we utilize opportunities to transition our system to not just maintain the status quo, but even adapt to produce a more normatively positive outcome altogether?

Any ecosystem resilience effort must incorporate the realities of adaptation, transitions, and transformations as a foundational component of evolutionary biology. Ecosystems are constantly in flux and adapting to new stimuli – some of which have the potential to remove it from one point of equilibrium to another. Sometimes this is relatively simple – an oil spill can be cleaned up, and its harms addressed through intense bioremediation over a few months. Other times this is quite difficult, such as the many steps needed to address harmful algal blooms in environmentally sensitive waters or to remove tons of plastic waste from ocean gyres. In ecological and environmental management, it is essential not only to identify the opportunities for such transitions, but to accurately characterize the drivers which could influence a local ecosystem away from a harmful or normatively negative basin of attraction, and towards one more beneficial to human and environmental health.

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