‘Black Swans’, ‘Dragon Kings’ and Beyond: Towards Predictability and Suppression of Extreme All-Hazards Events Through Modeling and Simulation

Anthony J. Masys, Eugene Yee and Andrew Vallerand

Abstract Shocks to regional, national and global systems stemming from natural or man-made hazards can have dramatic implications. Disasters such as Katrina (2005), Hurricane Sandy (2012), Alberta (Canada) Floods (2013), and Super Typhoon Haiyan (2013) are examples that highlight the vulnerability of communities to natural hazards and the crippling effect they have on the social and economic well-being. Through foresight and scenario planning, such events can be expected but can they be predicted to support resilience and enable suppression of the impacts? With consideration of emerging and systemic risks and inherent uncertainty associated with surprising events, planning for and managing risk, crisis and disasters requires understanding of the outliers that challenge our resilience. ‘Black Swans’ represent the unpredictable. They represent “… our misunderstanding of the likelihood of surprises” (Taleb in The black swan: the impact of the highly improbable, 2007). A ‘Black Swan’ is described by Taleb (2007) as that which is an outlier, that which is outside the realm of regular expectations which carries with it an extreme impact such as natural disasters, market crashes, catastrophic failure of complex socio-technical systems and terrorist events such as 9/11. Sornette (Int J Terraspace Sci Eng 2(1):1–18, 2009) identifies a different class of extreme events (outliers) that he calls ‘Dragon Kings’. Sornette (2009) argues that Dragon Kings may have properties that make them not only identifiable in real time but also predictable. The evolving science on complexity (and, more specifically, on complex networks) and on resilience suggest that modeling and simulation of such extreme events can assist in the predictability and the suppression of low probability extremely high consequence events such as natural hazards (flood, earthquake, wildfire, tsunami, extreme weather), cyber-attacks, and financial events. Furthermore, the science of complex networks is developing rapidly and has
fundamentally reshaped our understanding of complexity, potentially leading to innovative methods for the prediction of emergent behavior on natural and technological networks, as well as specific strategies for designing networks that are more resistant (resilient) to both failure and attack. Governments and owners of critical physical and digital infrastructure may benefit from analyses, advice and exercises that involve predictable and suppressible “Dragon-King” type of low probability extremely high consequence extreme events, as well as from the utilization of recent advances in complex network theory, to ultimately enhance resiliency. This chapter contributes to the discourse on Dragon Kings arguing for continued and concerted efforts to explore this domain.

Keywords Dragon King · Black Swan · Modeling · Simulation · Disasters · Natural hazards · Risk · Capability · Complexity · Complex networks · Emergency management · Emergency response · Emergency recovery · Homeland security

1 Introduction

Typhoon Haiyan (2013) devastated portions of south-east Asia and was one of the most intense storms ever documented. The Great East Japan Earthquake (2011) was the most powerful earthquake ever recorded to have hit Japan. The earthquake triggered powerful tsunami waves that reached heights of up to 40.5 m. The earthquake and tsunami caused extensive and severe structural damage to north-eastern Japan and resulted in the meltdown of three nuclear reactors. These events and others such as Hurricane Katrina (2005), Blackout Canada-US (2003), Hurricane Sandy (2012), Alberta (Canada) floods (2013), Heartbleed cyber incursion (2014) and global terrorist actions highlight the vulnerability of social and critical infrastructures to natural hazards, natural hazard triggered technological disasters (NATECHs) and man-made disasters and the crippling effect that such events can have regionally, nationally and globally on social and economic well-being (Masys et al. 2014). This networked risk landscape is one characterised by hyper-risks (Helbing 2013) and hybrid risks (Masys et al. 2014). As noted in Weick and Sutcliffe (Weick and Sutcliffe 2007), ‘Unexpected events often audit our resilience’ and thereby challenge response and recovery activities. With our hyper-connected world, the impact of unexpected events such as floods, earthquakes, financial crises, and cyber-attacks has revealed the fragility and vulnerabilities that lie within the social/technological/economic/political/ecological interdependent systems (Masys et al. 2014). In particular, events that impact physical and digital critical infrastructure such as damage to electric power, telecommunications, transportation and water-supply systems can ripple across local, regional and global regions. There exists a rich body of knowledge regarding the statistics associated with the occurrence of such outlier events. Taleb (2007) calls
these extreme events ‘Black Swans’ to describe their inherent quality of surprise, sometimes viewed as an ‘Act of God’. The question arises: can we predict the occurrence of some Black Swans’ (extreme events)? As described by Johnson and Tivnan (2012) ‘…understanding, controlling and predicting extreme behavior is an important strategic goal to support resilience planning’. As noted by Sornette (2009).

…extreme events should be considered to be rather frequent and to result from the same organization principle(s) as those generating other events: because they belong to the same statistical distribution, this suggests common generating mechanism(s).

Outliers that represent those extreme events that exist beyond the extrapolation of power laws are referred to as “Dragon-Kings” (Sornette 2009) as differentiated from “Black Swans” (Taleb 2007). It has been suggested that evolving complexity science has enabled the modeling and the prediction of what many thought was not yet predictable. Chikumbo et al. (2014) describe efforts to predict and influence (suppress) catastrophic events. The ‘dragon-king’ research of Sornette (2009) and Cavalcante et al. (2013) figure prominently. Chikumbo et al. (2014) describe how Cavalcante et al. (2013) set out to demonstrate the predictability of extreme events and how they can be suppressed by applying tiny perturbations to a system composed of coupled chaotic electronic oscillators. Dai et al. (2013) experimented with budding yeast to show that critical slowing down and/or increased variability of measurable system quantities near the bifurcation point holds the key to forecasting an impending event.

Moving beyond chaos theory and the quantification of emerging patterns in self-organizing systems, the new science of complex networks (that are ubiquitous in natural and technological systems) promises to provide a unifying paradigm for the development of a full-blown theory of complexity (which is certainly one of the grand challenges for 21st century science) (Barabasi 2003; Caldarelli 2007; Newman et al. 2006). Moreover, nascent efforts have been made to apply to complex network theory to obtaining a deeper fundamental understanding of the collective responses of human populations to large-scale emergencies such as bombings, plane crashes, earthquakes, and power outages (blackouts) (Bagrow et al. 2011) with important implications for improvements in emergency detection and response. Finally, very recent efforts on the application of control theory to complex networks (Liu et al. 2011) has been initiated, and this seminal effort is expected to have a potential long-term impact for the improvement of the robustness of technological and infrastructure networks against failures and attacks.

Such results suggest applications to the disaster management domain. Through the lens of these various emerging and evolving paradigms of complexity science and the application of modeling and simulation (M&S), insights can be derived that can uniquely inform disaster risk reduction through anticipation, avoidance or mitigation of systemic risks associated with such outlier disasters.
2 Black Swans, Dragon Kings and Beyond

Sornette (2009) argues that extreme events (high Impact, low probability) are amalgamated in the population of other events described by a power law distribution, ‘…the common wisdom is that there is no way to predict them because nothing distinguishes them from their small siblings: their great sizes and impacts come out as surprises, beyond the realm of normal expectations’. What differentiates Dragon Kings from Black Swans is that these particular extreme events are distinguishable by their sizes or by other properties from the rest of the statistical population. Sornette (2009) argues that Dragon-Kings ‘… result from mechanisms that are different, or that are amplified by the cumulative effect of reinforcing positive feedbacks’.

Sornette (2009) presents a generic phase diagram to explain the generation of Dragon-Kings and documents their presence in six different examples (distribution of city sizes, distribution of acoustic emissions associated with material failure, distribution of velocity increments in hydrodynamic turbulence, distribution of financial drawdowns, distribution of the energies of epileptic seizures in humans and in model animals, distribution of the earthquake energies). What emerges from the discussion is the association of Dragon-Kings with such dynamics as ‘… a phase transition, a bifurcation, a catastrophe, or a tipping point’ (Sornette 2009). Hence, Sornette (2009) argues that the presence of a phase transition provides foresight ‘weak-signals’ pertaining to the occurrence of Dragon-Kings. What this suggests from a disaster risk reduction perspective, is that through modeling efforts, extreme events (Dragon Kings) ‘… can exhibit a degree of predictability’ (Johnson and Tivnan 2012) thereby supporting planning and mitigation of risks. In essence, it is argued that through M&S we can proactively examine conditions of vulnerability to decrease the likelihood and/or impact of extreme events (dragon-kings) through scenario analysis. This is essentially a ‘flight simulator’ framework to test drive and explore different scenarios to facilitate decision making.

In a broader perspective, modern societies and the engines of civilization are built on an intricate framework of diverse networks—various economic, infrastructure and technological networks such as enormous networks of power stations, intricate transport networks, comprehensive communication networks, financial markets, and the Internet to name but a few, which are all built up of many (relatively) simple components (agents such as humans, power stations, businesses, airports, etc.) that interact with each other leading to patterns of interaction exhibiting extreme (unlimited) complexity and potentially resulting in emergent forms of behavior that are difficult (if not impossible) to predict. The dependencies of the various components of a network on each other only become clear when failures (catastrophes) occur in the network such as the rapid spreading of a computer virus over the Internet, the collapse of a global financial system, or the large-scale breakdown of an electrical power grid. Yet, researchers (Barabasi 2003; Caldarelli 2007; Newman et al. 2006) are discovering general concepts and properties that appear to be intrinsic to the various diverse complex networks, leading to
the intriguing concept that there may be a few fundamental organizing principles that determine the topological characteristics and ultimately the behavior of complex networks. In other words, there may be a set of basic universal rules (generic organizing principles) that would allow one to predict the emergent behavior in a complex network (despite the seemingly intractability of this enormous task) which according to Barabasi (2005) would allow one ‘… to understand the key to nature’s code for multitasking—the one that orchestrates the actions of uncountable components into a magic dance of order and ultimate elegance’.

3 Predictions and Suppression?

Extreme behaviors, such as those exhibited by financial crashes, flooding (Alberta, 2013), earthquake triggered disasters (Fukushima, 2011) emerge spontaneously across a wide range of natural, biological and socio-economic domains. However, from the economic domain, weak signals (warning signs) have been flagged that suggest emerging dramatic changes in the global financial markets. Johnson and Tivnan (2012) describe how on 6 May 2010, ‘…it took just 5 min for a spontaneous mix of human and machine interactions in the global trading cyberspace to generate an unprecedented system-wide Flash Crash. For reasons which are still not entirely clear, the interaction between the global ecology of market participants (both human and computer trading algorithms) was able to produce a self-induced extreme change which had no definitive nucleating event, and yet drove the market to values it would ordinarily never reach—all within a few minutes’.

Mitigating the impacts of extreme events rests on the ability that encompasses anticipation and preparedness. Alfieri et al. (Alfieri et al. 2013) describe the success of the Global Flood Awareness system (GloFAS) in terms of predictability. Their research has shown that ‘… hazardous events in large river basins can be skillfully detected with a forecast horizon of up to 1 month. In addition, results suggest that an accurate simulation of initial model conditions and an improved parameterization of the hydrological model are key components to reproduce accurately the streamflow variability in the many different runoff regimes of the earth’ (Alfieri et al. 2013). It was reported that “… ten days before Calgary was inundated last summer, supercomputers half a world away were spitting out predictions that showed the city would soon be flooded” (McClure 2014).

Catastrophic events such as that experienced through Katrina (2005) and Fukushima (2011) involve interactions between structures at many different scales. Hurricane Katrina (2005) devastated New Orleans thereby revealing inherent vulnerabilities that resided in the socio/political/ecological/technical infrastructure (system) of the city and the nation. As described in Masys (2014a), these ‘unseen’ vulnerabilities that emerged at the ‘seams’ of interconnection and interdependencies
can be characterized as ‘resident pathogens’, in that the hurricane as a ‘triggering mechanism’ interacted with the ‘… city’s fragile physical environment, aging infrastructure, and declining economic and social structure’ (Comfort 2006) as well as policies, regulations and politics. Comfort (2006) asks the question ‘Was the damage in New Orleans due to Hurricane Katrina, or was it some combination of human and technical factors that failed under the stress of the hurricane?’ Applying the notion of complex systems to the Hurricane Katrina case highlights the interdependencies, interconnectivities and inherent non-linearity that preclude ‘linear, experience-based or intuitive approaches’ (Helbing 2010) to disaster management.

Dragon-kings emerge from such complex systems characterized by such mechanisms as ruptures, phase transitions, bifurcations, catastrophes, and tipping points. The significance of this to disaster management is that such phase transitions often take planners by surprise ‘… because of the ubiquitous tendency to extrapolate new behavior from past ones’ (Sornette 2009). Sornette (2009) presents examples in the field of material science and financial economics whereby recognizing the role of phase transitions ‘… allow us to unify different regimes under a synthetic framework, sometimes with encouraging potential for prediction of crises’. That being said, Sornette (2009) is cautious to emphasize ‘… that there is no unique methodology to diagnose dragon-kings. One needs a battery of tools’. Dragon-kings can be observed:

- sometimes directly, in the form of obvious breaks or bumps in the tail of size distributions;
- through the construction of novel observables, which are more relevant to the dynamics of the system; and/or
- through comparison of distributions obtained at different resolution scales that allows one to diagnose the existence of a population of dragon-kings (Sornette 2009).

Hence, M&S and analysis tools and methodologies such as that in Table 1 have been shown to provide value and support disaster risk reduction through the diagnosis of extreme events.

It is emphasized by Janczura and Weron (2012) that the qualification of dragon-kings as described by Sornette (2009) is strongly model dependent. Sornette (2009) does present supporting evidence for the concept that meaningful outliers (called “dragon-kings”) exist and through the analysis of the characteristics and dynamics of these events one can ‘… learn how to diagnose in advance the symptoms of the next great crisis’. Nonetheless, it is the disciplined exploration of the regime of extreme events through modeling and simulation that is the key message to support disaster risk reduction. Such supporting methods as scenario planning (Masys 2012) and vulnerability analysis leveraging complexity theory and systems thinking (Masys 2013, 2014a, b) figure prominently in analyzing the cascading effects of shocks to systems.
Complexity theory emerges as a key lens to better understand extreme events. It recognizes the interdependencies and interconnectivity that characterizes these extreme events. Such extreme events cannot be inferred from the properties of their parts; hence local events can have far-reaching consequences that are often difficult to anticipate. The question is posed by Sornette and Ouillon (2012) as to how much the understanding obtained on dragon-kings could lead to operational utility. To this, Janczura and Weron (2012) find such a notion controversial, but nonetheless do not outright discount it, but rather call for more research. Sornette and Ouillon (2012) describe the value of modeling and simulation to explore this regime of complexity, and particularly to support decision making. Their analysis of this domain highlight that failures such as Deepwater Horizon Oil spill (Masys2012; Wattie and Masys2014) and subprime crisis, exhibit common patterns including: ‘lack or decreasing questioning of assumptions over time; insufficient prior analysis; failure to anticipate side effects; incorrect interpretation of the system’s reaction (no immediate obvious negative effect wrongly interpreted as “all is well”)’ (Sornette and Ouillon2012). This resonates with such Natural Disaster Triggered Technological Accidents as the Fukushima Daiichi nuclear disaster (Ray-Bennett et al.2015), as well as humanitarian crisis (Masys2013) and violent extremism and radicalization (Masys 2014b). In these analysis and simulations, complex interdependencies and nonlinearity characterize the problem space. Weak signal detection emerges as requirement to facilitate management of such disasters. Suveges and Davison (2012) present an example of a catastrophic event (extreme rainfall) that was apparently impossible from scientific extrapolation or common sense based on the past. In effect, disaster risk reduction through modeling and simulation support planning for and mitigating these types of extreme events.

Sornette and Ouillon (2012) are adamant that the cost is too large to learn from real-life crises. They argue that ‘… it is possible to develop simulators for decision makers to understand the complex dynamics of out-of-equilibrium systems whose behavior intrinsically includes changes of regimes, bifurcations, tipping points and their associated dragon kings’.

| Table 1 Managing complexity: a suite of related M&S tools and methodologies |
|---------------------------------|---------------------------------|
| Large-scale data mining         | Complex networks                |
| Complex networks                | System dynamics                 |
| Scenario modeling               | Agent-based modeling            |
| Sensitivity analysis            | Catastrophe theory              |
| Systems theory                  | Statistical analysis of extreme events |
| Non-linear dynamics and chaos theory | Complexity theory             |
The decision maker thus first needs to understand the dynamics of his system holistically, in a systemic way, which means that he needs to understand the existence of dragon-kings as one of the dynamical solutions of the evolution of his system. He needs to have a classification of the different regimes possible, a phase diagram in which he understands which control leads to the region of the dragon-kings and which do not. He needs to understand that bifurcations and changes of regime are a natural and expected part of natural and social systems (Sornette and Ouillon 2012).

The rapid advances in complex network science may lead in the early part of the 21st century to the discovery of common operating principles governing the behavior of diverse networks (Barabasi 2005) whose basic understanding would allow not only the prediction of the emergent and complex behavior arising from the interactions of the individual units in a large system, but also the development of a range of specific strategies to defend the network against either a failure or an attack (e.g., stopping the spread of an epidemic on a human or computer network) providing potentially significantly improved resiliency in response to disasters (e.g., global epidemics such as SARS and Ebola, large electrical blackouts, computer viral epidemics such as the Blaster and SoBig worms). For example, some initial seminal work (Liu et al. 2011) has already been conducted to determine the degree of controllability of some real networks. This effort can potentially lead to the development of a tool box that can be applied to the control of arbitrary complex networks, providing a framework to increase the robustness of a network to failures or to an attack (viz., to better resist random or intentional attacks). Finally, new avenues involving novel concepts of multiscale connectivity within networks (Dodds et al. 2002) have been shown to possess the characteristic of ultra-robustness by simultaneously minimizing the likelihood of failure (i.e., avoiding the failure) in the network as well as the effect of the failure if and when this occurs (i.e., minimizing any further loss from the failure if it should occur). Ultra-robustness is a key determinant in the characterization of a complex network with respect to catastrophe recovery whether from a failure or from an attack. Another interesting application of complex network theory is to the prediction of human mobility (Song et al. 2010) and, more specifically, to the deeper understanding of the role and impact of human dynamics and activity patterns in emergency detection and response (Bagrow et al. 2011). Network thinking described by (Masys et al. 2014) figure prominently as a paradigm for examining black swan, dragon king and extreme events.

The complexity arises from the inherent interdependencies and interconnectivity resulting in an entangled state of relations and a causal chain that is non-linear. Hence, models and simulations inform risk awareness thereby supporting disaster risk reduction. Systemic risks emerge from our hyper-connected world. These risks are no longer contained geographically or temporally but are transnational. These risks are characterized by their apparent uncertainty and ambiguity and emerge as complex (multi-causal). M&S can be used to explore this very regime and characteristics.
4 Conclusion

Though “Black Swan” events in regional, national and global systems can be viewed as an unpredictable “Act of God”, there is a type of extreme event that appears to be predictable and thus suppressible: the “Dragon-King” event. Modeling and simulation of such extreme events can assist in the predictability and the suppression of some low probability extremely high consequence events such as natural hazards (flood, earthquake, wildfire, tsunami, extreme weather), cyber-attacks, financial events, mass crowd evacuation. However, this positive view should be balanced by ‘the fact that this remains a very delicate and difficult field, if only due to the scarcity of data as well as the extraordinary important implications with respect to hazard assessment, risk control and predictability’ (Sornette and Ouillon 2012). Addressing the Dragon-Kings and Black Swans to support disaster risk reduction requires embracing the inherent uncertainty, complexity, and ambiguity that characterizes the problem space. Hence the application of M&S tools and techniques coupled with involvement of experts, stakeholders and the public can provide insights and unique and timely advice to support disaster risk reduction and the resulting risk handling and response strategies. Furthermore, emerging research areas focused on the elucidation of some fundamental organising principles that govern the behavior of diverse networks may confer significantly improved predictive power in a theory of complexity, and this increased understanding of natural or technological networks may facilitate the design of network topologies that are much more tolerant to both failure and attack. Emergency Managers in Governments and owners of critical physical and digital infrastructure may benefit from analyses, advice and exercises that involve predictable and suppressible “Dragon-King” type of low probability extremely costly and extremely high consequence events, as well as from recent advances in complex network theory, to ultimately enhance resiliency.

References

Alfieri L, Burek P, Dutra E, Krzeminski B, Muraro D, Thienen J, Pappenberger F (2013) GloFAS —global ensemble streamflow forecasting and flood early warning. Hydrol Earth Syst Sci. 17:1161–1175. doi:10.5194/hess-17-1161-2013, www.hydrol-earth-syst-sci.net/17/1161/2013/
Bagrow JPD, Wang D, Barabasi A-L (2011) Collective response of human populations to large-scale emergencies. PLoS ONE 6(3):e17680. doi:10.1371/journal.pone.0017680
Barabasi A-L (2003) Linked: the new science of networks. Plume Books, Cambridge
Barabasi A-L (2005) Taming complexity. Nat Phys 1:68–70
Caldarelli G (2007) Scale-free networks. Oxford University Press, London, p 2007
Chikumbo O, Lewis S, Canard H, Norris T (2014) Futuristic smart architecture for a rapid disaster response. In: Masys AJ (ed) Disaster management-enabling resilience. Springer, Berlin
Comfort LK (2006) Cities at risk: Hurricane Katrina and the drowning of New Orleans. Urban Affairs Review
Dai L, Vorselen D, Korolev KS, Gore J (2013) Generic indicators for loss of resilience before a tipping point leading to population collapse. Science 336:1175–1177

Cavalcante HLDS, Oriá M, Sorrette D, Ott E, Gauthier DJ (2013) Predictability and suppression of extreme events in a chaotic system. Phys Rev Lett 111(198701):2013

Dodds PS, Watts DJ, Sabel CF (2002) The structure of optimal redistribution networks. Institute for Social and Economic Research and Policy Working Paper, Columbia University

Helbing D (2010, Oct) Systemic risks in society and economics. IRGC—emerging risks, Helbing

Helbing D (2013) Globally networked risks and how to respond. Nature 497:51–59

Janczura J, Weron R (2012) Black swans or dragon kings? A simple test for deviations from the power law. Eur Phys J Special Topics 205:79–93

Johnson N, Tivnan B (2012) Mechanistic origin of dragon-kings in a population of competing agents. Eur Phys J Special Topics 205:65–78

Liu Y-Y, Slotine J-J, Barabasi A-L (2011) Controllability of complex networks. Nature 473:167–174

Masys AJ (2012) Black Swans to Grey Swans—revealing the uncertainty. Int J Disaster Prev Manage 21(3):320–335

Masys AJ (2013) Human security—a view through the lens of complexity. In: Gilbert T, Kirkilions M, Nicolis G (eds) Proceedings of the European conference on complex systems 2012. Springer proceedings in complexity, pp 325–335

Masys AJ (2014a) Critical infrastructure and vulnerability: a relational analysis through actor network theory. In: Masys AJ (ed) Networks and network analysis for defence and security. Springer, Berlin

Masys AJ (2014b) Radicalization and recruitment: a systems approach to understanding violent extremism. Int J Syst Soc

Masys AJ, Ray-Bennett N (2015) Network thinking: understanding interdependencies and interconnectivity to support vulnerability analysis and DRR. Presented at UN World conference on disaster risk reduction, Sendai, Japan, 14–18 Mar 2015

Masys AJ, Ray-Bennett N, Shiroshita H, Jackson P (2014) High impact/low frequency extreme events: enabling reflection and resilience in a hyper-connected World. In: 4th international conference on building resilience, 8–11 Sept 2014, Salford Quays, UK (Procedia Economics and Finance 18:772–779)

McClure M (2014) Computer model forecast flooding in Calgary 10 days before deluge. Calgary Herald. http://www.calgaryherald.com/news/Computer+model+forecast+flooding+Calgary+days+before+deluge/9488235/story.html

Newman MEJ, Barabasi A-L, Watts DJ (2006) The structure and dynamics of complex networks. Princeton University Press, Princeton

Ray-Bennett N, Masys AJ, Shiroshita H, Jackson P (2015) Reactive to pro-active to reflective disaster responses: introducing critical reflective practices in disaster risk reduction (DRR). In: Collins AE, Samantha J, Manyena BS, Jayawickrama J (eds) Natural hazards, risks, and disasters in society: a cross-disciplinary overview. Elsevier Inc, Amsterdam

Song C, Qu Z, Blumm N, Barabasi A-L (2010) Limits of predictability in human mobility. Science 327:1018–1021

Sornette D (2009) Dragon-Kings, Black Swans and the prediction of crises. Int J Terraspace Sci Eng 2(1):1–18 (http://arXiv.org/abs/0907.4290)

Sornette D, Ouillon G (2012) Dragon-kings: mechanisms, statistical methods and empirical evidence. Eur Phys J Special Topics 205:1–26

Suveges M, Davison AC (2012) A case study of a dragon-king: the 1999 Venezuelan catastrophe. Eur Phys J Special Topics 205:131–146

Taleb NN (2007) The Black Swan: the impact of the highly improbable. Penguin Books Ltd, London
Wattie J, Masys AJ (2014) Enabling resilience: an examination of high reliability organizations and safety culture through the lens of appreciative inquiry. In: Masys AJ (ed) Disaster management—enabling resilience. Springer, Berlin
Weick KE, Sutcliffe KM (2007) Managing the unexpected: resilient performance in an age of uncertainty, 2nd edn. Wiley, San Francisco