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### **Abstract**

As defined by Nassim Nicholas Taleb, a “Black Swan” is an extremely rare but highly impactful event. Reliance on prior knowledge to conclude that a Black Swan event could never occur is a logical fallacy, and when such an event does happen human nature inclines us to devise a reasonable post-hoc explanation that makes it seem more predictable in hindsight. Because Black Swans are so uncommon and their features are unknowable, preparing for them may be neither rational nor efficient; yet, ignoring them entirely could prove catastrophic. As a result, Black Swans present a conundrum for risk management and the protection of critical infrastructure. Some social science research has examined extremely rare events and people’s responses to them, but conventional approaches to understanding patterns in human behavior often break down when applied in this context. This report aims to: (1) define the concept of Black Swans in theoretical terms, highlighting several prominent examples of high-impact/low-probability threats to critical infrastructure (e.g., terrorist attacks, natural disasters, and pandemics); (2) briefly review the existing research from several social science disciplines that has focused on rare events; and (3) discuss some proposed strategies for reducing uncertainty in decision-making and preventing cascading failures.

**Keywords:** Black Swans, rare events, critical infrastructure, risk management, disasters

## Introduction

Before Willem de Vlamingh discovered black swans in Australia in 1697, everyone in the Old World believed all swans to be white. All empirical evidence supported this supposition. Further, because they encountered white swans only, Europeans had not even conceived of the possibility that swans *could* be black, thereby revealing the tenuous nature of understanding rooted in observation. This famous example of upended expectations has “developed to mean not only something extremely rare...but also that a perceived impossibility might later be disproven: a logical fallacy, meaning that if one does not know about something, it is therefore impossible” (Aven, 2013, p. 44). Nassim Nicholas Taleb (2007, 2010) uses the Black Swan as a metaphor for the incomplete and flawed ways that humans understand risk, explain social and natural phenomena, develop theories, and prepare for the future. Moreover, Taleb’s overarching perspective is that human history is driven mostly by a small number of impactful Black Swans rather than the accumulation of ordinary events, and he argues that attempts by social scientists to predict or explain Black Swans in hindsight are futile.

Taleb (2007) extends the logical-philosophical puzzle of the Black Swan to emphasize the “fragility of knowledge about the tails of the distributions in domains where errors can be consequential” (p. 200). For extremely rare events, there is almost always insufficient data to make plausible predictions and evidence-based decisions, which means that conventional approaches are guided by a mixture of incomplete information and guesswork (Freedman & Stark, 2003; Krantz, 1998; Taleb, 2005). For this reason, Taleb (2007) is critical of “reliance on probability in domains where the current methods can lead us to make consequential mistakes...where, on logical grounds, we need to force ourselves to be suspicious of inference about low probabilities” (p. 198). However, despite our general inability to predict or explain

data points on the tails of statistical distributions, these extremely rare events are the ones that often carry the most impactful consequences (Aven, 2015; Runde, 2009). Accordingly, Taleb (2010) defines a “Black Swan” in the following terms:

First, it is an *outlier*, as it lies outside the realm of regular expectations, because nothing in the past can convincingly point to its possibility. Second, it carries an extreme impact (unlike the bird). Third, in spite of its outlier status, human nature makes us concoct explanations for its occurrence *after* the fact, making it explainable and predictable... A small number of Black Swans explain almost everything in our world, from the success of ideas and religions, to the dynamics of historical events, to elements of our own personal lives. (p. xxii)

A central thesis of Taleb’s book is that traditional social science approaches to studying and theorizing about human behavior and experiences overemphasize normal patterns and thus underemphasize the role of Black Swans. Indeed, Taleb (2005, 2010) is highly skeptical of attempts to devise narrative explanations of historical accidents, as the unknowable nature of Black Swans places them at odds with methods rooted in the analysis of observable and predictable data points. Though the “Black Swan” concept and its implications have come under scrutiny (e.g., Callahan, 2009; Mueller & Stewart, 2016; Werther, 2013), it remains the case that conventional ways of understanding social phenomena are not well suited to explain rare events and idiosyncratic behaviors (Griffin & Stitt, 2010; Harding et al., 2002; Miccio-Fonseca, 2023; Sauder, 2020). Further, some scholarly attention has been focused on how individuals act when presented with choices that carry a low probability of catastrophic loss (Bonini et al., 2019; Hertwig et al., 2004; Perfors & Van Dam, 2018), and this line of inquiry can help advance our understanding and appreciation of Black Swans beyond Taleb’s description of them.

The Black Swan concept is widely applicable to numerous fields of study (see, e.g., Anderson et al., 2017; Bekiros et al., 2017; Marmai et al., 2022), though these ideas have particularly important practical implications for risk management and the protection of critical infrastructure. In fact, the most prominent examples of Black Swans discussed by Taleb and others include acts of terrorism, natural disasters, and pandemics—events that are consequential because they can produce catastrophic destruction and precipitate cascading infrastructure failures. In discussions of how Black Swans may be prevented and their harmful effects mitigated, some professionals agree with Taleb that attempts to predict and explain Black Swan events are inherently flawed (Nafday, 2009; Wardman & Mythen, 2016). Many others, however, have argued that Black Swan events are mythical insofar as they are unpreventable, and they propose several strategies that aim to improve knowledge about the unknown, call attention to “emerging risks,” and utilize measurable indicators of vulnerability (e.g., Cooper & Eschleman, 2021; Flage & Aven, 2015; Krausmann & Necci, 2021; Murphy & Conner, 2014).

### ***Problem Statement and Research Objective***

The aim of this report is threefold. First, I discuss Taleb’s (2007, 2010) concept of Black Swans, the three properties that characterize these events, and efforts among scholars to apply this definition to specific incidents. Second, I highlight the difficulties that emerge when social scientists explore case studies and rare events, and I review some research on the decision-making of individuals when presented with Black Swan scenarios. Finally, I summarize some recommendations from studies of risk management and critical infrastructure protection on how Black Swan events may be best anticipated and responded to. By integrating scholarship across multiple disciplines that has been inspired by Taleb’s work, this report is intended to provide an informational resource for policymakers, professionals, and members of the public.

## **Defining and Conceptualizing “Black Swans”**

Taleb’s (2005, 2007, 2010) principal idea is rooted in the notion that “the future cannot be forecast, and especially that large impact, large scale, rare events (LSLIRE) and their implications, cannot be foreseen” (Werther, 2013, p. 13). Indeed, he argues that much about the world is unpredictable, and thus there is a disjuncture between the features of socio-economic phenomena and the methods used by well-meaning people to understand and forecast them. Taleb (2010) defines Black Swans as having three key properties: (1) rarity, (2) extreme impact, and (3) dubious retrospective predictability despite insistent claims to the contrary. Taleb’s work has received considerable acclaim and spurred calls among social scientists to better consider the role of randomness in social life (e.g., Griffin & Stitt, 2010; Sauder, 2020). Nonetheless, many scholars have criticized the concept of the Black Swan, speculated about the “unknowns” and “consequences” that meet Taleb’s definition, debated about specific historical incidents that may or may not be considered Black Swans, and questioned whether the total abandonment of pattern-based approaches to minimizing risk is misguided (e.g., Aven, 2013; Callahan, 2009; Mueller & Stewart, 2016; Runde, 2009).

### ***Property #1: Rarity***

As discussed above, Taleb (2007, 2010) uses the concept of the Black Swan to describe high-impact, extraordinary events that defy conventional predictive models due to their rarity. At the heart of the Black Swan metaphor is the unexpected nature of the event; extremely rare data points are often not captured, thus undermining the efficacy and usefulness of statistical methods used to calculate likelihood based on existing data (Aven, 2015; Chichilnisky, 2010; De Marzo et al., 2022). Further, Black Swans have highly consequential outcomes, and these asymmetries between probability and importance can be overlooked. As Paté-Cornell (2012) explains:

Normal (Gaussian) distributions are generally insufficient to describe such uncertainties because they assume symmetry and do not generally represent the “fat tails” of loss distributions. Gaussians are sometimes used to add a “fudge factor” to a quantity instead of representing the actual state of information about it, without fundamental reason for the distributions’ shape and symmetry. (p. 1824)

The difficulties associated with using observed data to predict unobserved events is not a new idea, as it is central to David Hume’s (1748/1999) “problem of induction”—we cannot infer general rules based only on observed facts that may yet be disproven. In a risk management context, unforeseen threats as well as previous Black Swans that are unlikely to occur again arguably provide an irrational basis for action (Aven & Krohn, 2014; Lyon & Popov, 2022).

Though all Black Swans represent random deviations from normal expectations, not all such deviations are Black Swans. According to Taleb (2007, 2010), the rather predictable forms of extreme deviation in some domains (i.e., “Mediocristan”) are qualitatively different from the highly unpredictable and impactful deviations (i.e., “Extremistan”) of which Black Swan are a type. As Taleb (2010) writes, “For an event to be a Black Swan, it does not just have to be rare, or just wild; it has to be unexpected, has to lie outside our tunnel of possibilities” (p. 213). Along these same lines, Paté-Cornell (2012) distinguishes between *aleatory* uncertainties, which stem from a confluence of rare but known events, and *epistemic* uncertainties (i.e., true Black Swans) that represent a lack of fundamental knowledge. Thus, Black Swans are often described as “unimagined eventualities” (Runde, 2009) or “unknown unknowns” (Ale et al., 2020; Aven, 2013, 2015). This category stands in contrast to “known unknowns” (i.e., things that are hidden but which we are aware of) and “unknown knowns” (i.e., things that are known to others but which we have forgotten or are not aware of).

Importantly, the notion that Black Swans are so improbable as to be unforeseeable does not mean that such events are impossible (Ale et al., 2020; Lyon & Popov, 2022). Yet, the specific historical events that may be identified as fitting this criterion are disputed for several reasons. First, disasters that were not specifically anticipated yet were generally not considered implausible (e.g., the attack on Pearl Harbor, Hurricane Katrina, the Japanese tsunami of 2011) are sometimes classified as Grey Swans (i.e., “known unknowns”) rather than Black Swans. Second, for some high-impact events (e.g., the subprime mortgage crisis of 2007), the absence of forehand knowledge among members of the general public does not preclude such an awareness among experts (Runde, 2009; Taleb, 2010). Finally, as discussed below, hindsight bias can make events seem more predictable (e.g., the 9/11 terrorist attacks), thus distorting retrospective assessments of probability (Catalano et al., 2018; Lindaas & Pettersen, 2016; Nafday, 2009). As a result of these factors, the “Black Swan” concept seems vulnerable to the “no true Scotsman” fallacy, as “it is difficult to nail down exactly what a ‘Black Swan’ is under Taleb’s definitions” (Mueller & Stewart, 2016, p. 2).

### ***Property #2: Extreme Impact***

The second property of Black Swans is their extreme impact. The rare or unknowable features of the event are not sufficient to designate it as a Black Swan; however, these two properties are closely linked, as the more unpredictable the event, the stronger its consequences must be in order to capture public attention. On this point, Taleb (2010) states:

We in real life do not care about simple, raw probability (whether an event happens or does not happen; we worry about consequences (the size of the event; how much total destruction of lives or wealth, or other losses, will come of it; how much benefit a beneficial event will bring). Given the less frequent the event, the more severe the

consequences (just consider that the hundred-year flood is more severe, and less frequent, than the ten-year flood; the bestseller of the decade ships more copies than the bestseller of the year), our estimation of the *contribution* of the rare event is going to be massively faulty (contribution is probability times effect; multiply that by estimation error); and nothing can remedy it. (p. 351)

It is important to emphasize that Black Swans can have impacts that are either highly positive or highly negative. While some industries involve less upfront risk but great reward in rare cases, “a negative-Black Swan business is one where the unexpected can hit hard and hurt severely” (Taleb, 2010, p. 207). Further, Taleb (2010) argues that “in general, positive Black Swans take time to show their effect while negative ones happen very quickly—it is much easier and much faster to destroy than to build” (p. 45). Accordingly, negative Black Swans represent the primary focus of the discussion in the final section of this paper.

To categorize the impact of a Black Swan as highly consequential requires a value-judgment, as there are “no absolute, observer-independent standards for what counts as ‘an extreme impact’” (Runde, 2009, p. 496). For instance, while there is little debate about whether the 9/11 terrorist attacks or the Great Recession were consequential, such a distinction is less clear when the consequences are restricted to a certain field (e.g., the discovery of literal black swans to ornithology) or are felt only locally (e.g., certain natural disasters). Meeting this criterion is in large part dependent on people’s emotions and subjective perceptions that identify Black Swans as such (Aven, 2015; Krausmann & Necci, 2021; Runde, 2009). For this reason, Mueller and Stewart (2016) argue that people’s responses to events—rather than the events themselves—are what make them Black Swans. Not all impactful events are sudden (e.g., the rise of capitalism, improvements in human health and life expectancy), and not all culturally

memorable incidents carry long-term consequences (e.g., the sinking of the *Titanic*). To avoid these issues of tautology and selection bias, some have argued in favor of expanding the definition of Black Swans to include incidents that *could* have mobilized a substantial emotional response but failed to do so (Lindaas & Pettersen, 2016; Mueller & Stewart, 2016).

***Property #3: Seeming Retrospective Predictability***

Taleb's (2010) conceptualization of Black Swans as high-impact outliers highlights the measurable characteristics of the events themselves. However, the third property of Black Swans focuses instead on people's psychological responses Black Swans—how people respond to rarity and randomness when making sense of their own lives, patterns and relationships in the social world, and the arc of human history in general. Black Swans are ostensibly predictable in hindsight, and human nature inclines us to construct narratives rooted in confirmation bias that attempt to make sense of them (Ale et al., 2020; Catalano et al., 2018; Lindaas & Pettersen, 2016). Taleb (2010) describes the propensity to contrive logically cohesive stories to explain otherwise unexplainable events as the “narrative fallacy:”

The narrative fallacy addresses our limited ability to look at sequences of facts without weaving an explanation into them, or, equivalently, forcing a logical link, an *arrow of relationship*, upon them. Explanations bind facts together. They make them all the more easily remembered; they help them *make more sense*. Where this propensity can go wrong is when it increases our *impression* of understanding. (pp. 63-64).

Taleb's criticism of humans' proneness toward hindsight bias corresponds closely with his skepticism of analytic methods that rely on observed data to predict the unobservable. In fact, because many academic fields are built on the idea that insightful theories provide propositions that explain all human action, Taleb (2010) suggests a “need to downgrade ‘soft’ areas such as

history and social science to a level slightly above aesthetics and entertainment, like butterfly or coin collecting” (p. 172).

As discussed in more detail below, there is a growing appreciation among social scientists that some events do not fit within broader patterns and thus must be understood as random occurrences that lie beyond the explanatory power of models applied after the fact (Blyth, 2009; Runde, 2009; Sauder, 2020). However, this position also has drawn strong opposition (e.g., Callahan, 2009), not least because the predictive value of narrative explanations can be quite good when anticipating and explaining more mundane events. Thus, even if extremely consequential changes occur following highly unexpected incidents, conventional methods of understanding probability and risk need not be abandoned entirely (Mueller & Stewart, 2016). As Werther (2013) notes, “the fact that any, or all, individual sciences, methods, and models individually may fail to rightly warn and forecast is irrelevant to the claim that better forecasting cannot be done” (p. 7). Thus, the conceptualization of Black Swans overlooks the merits of iterative improvements to predictive models and the success of risk management approaches that anticipate imagined events (Lindaas & Pettersen, 2016; Paté-Cornell, 2012; Werther, 2013; Zuev & Kabalyants, 2022).

### **Social Science Research on Rare Events**

As previously discussed, extreme rarity and randomness are necessary but not sufficient conditions for an event to be considered a Black Swan. In the realm of conventional social science, how and why extremely rare, history-making events occurred is infrequently the primary focus of analysis. Nonetheless, methodological approaches in this regard do exist (see, e.g., Clemens, 2007; Griffin, 1993; Hirschman & Reed, 2014). Although analyses focused on societal-level Black Swans generally fall outside the domain of such fields as sociology and

criminology, it remains the case that many phenomena of interest that are experienced at the individual or community level are extremely rare. In quantitative analyses, predicting the probability of a rare event is challenging because the statistical methods used to estimate binary outcomes perform poorly under these conditions, necessitating corrections and/or alternative research designs (e.g., King & Zeng, 2001; Lacy, 1997). When addressing highly idiosyncratic events or units of analysis, case studies are often required; however, they are frequently maligned by scholars in the discipline (Pacewicz, 2022; Steinmetz, 2004).

A common critique of studies of unique, rare events is that they ineffectively allow researchers to draw inferences and generalizations about the total population from which a case was drawn (e.g., Donmoyer, 1990; Tsang, 2014). This limitation also extends to policy recommendations that are offered in light of case studies; for example, prevention strategies may apply only under the narrow set of circumstances which arose in the context of an extraordinarily rare incident (see, e.g., Harding et al., 2002; Kleck, 2009; Miccio-Fonseca, 2023). Indeed, as Taleb (2010) points out, Black Swans are extreme outliers that almost certainly have features that are not shared with other cases in the distribution. Nonetheless, these realities do not render systematic social observation useless but rather provide a fruitful line of inquiry. For example, Griffin and Stitt (2010) advocate for a “Black Swan criminology” (p. 62) that involves framing high-profile crime incidents as random tragedies that should not be used as the basis for law. Similarly, Sauder (2020) argues that sociology should more explicitly incorporate the concept of luck, which underlies many examples of “rags-to-riches” Black Swans:

Luck, however, is more than a folk concept. It is a real phenomenon in that people are subject to consequential chance events that are outside of their control. These events have the potential to affect individual outcomes, and it is possible that the effects of these

events are systematically conditioned by social position. As such, a second argument for studying luck focuses on what is lost when we exclude luck from our conceptual vocabulary. When sociology ignores the existence of luck or treats luck as if it has no analytic value, it affects both how inequality is studied within sociology and how the discipline portrays inequality to the public. (p. 200)

Finally, it may be informative to draw attention to insights from previous scholarship on how people make decisions given the possibility of negative Black Swans. There is limited research in this area, but the existing evidence suggests that people tend to vastly underestimate the likelihood of a catastrophic rare event and overestimate their own competence (Bonini et al., 2019; Hertwig et al., 2004). Further, people are not sensitive to differences between very small probabilities, and they can even choose the riskier of two options when the expected gains are higher (Perfors & Van Dam, 2018). Thus, prominent economic models of decision-making break down when individuals are faced with a choice involving a low likelihood of extreme negative utility; this is sometimes described as the “tyranny of catastrophic risks” (Buchholz & Schymura, 2012). Perfors and Van Dam (2018) discuss this problem thusly:

Representing the utility of black swan events as negative infinity means that one should devote infinite resources to ensuring that they do not happen. Conversely, if the probabilities of these events happening are small enough then any numerical values would effectively be ignored entirely. (p. 870)

### **Black Swans as Threats to Critical Infrastructure**

The Black Swans of primary interest to policymakers and members of the public are those which threaten to undermine various facets of critical infrastructure that allow modern social-economic systems to function effectively. For example, some terrorist attacks have been

designated as Black Swans, and the extent to which experts are able to anticipate when and where one will occur is a subject of intense debate (De Marzo et al., 2022; Lindaas & Pettersen, 2016; Mueller & Stewart, 2016). Additionally, certain natural disasters have been identified as Black Swans, though these incidents are generally considered Grey Swans because they fall within the realm of “known unknowns” (Lin & Emanuel, 2016; Masys, 2012). Finally, although several scholars (as well as Taleb himself) predicted that a pandemic was likely to occur, perhaps the most prominent recent example of a Black Swan is the COVID-19 pandemic (Antipova, 2021; Devarajan et al., 2023; Grossman et al., 2021; Murphy et al., 2020). These three types of Black Swans present the possibility of catastrophic loss and the initiation of cascading infrastructure failures, and how systems should best manage and prepare for the unpredictable is a paradox that risk management professionals must face.

The literature produced by industry professionals on Black Swans is largely unified by a shared theme; namely, that “Black Swans” are *not* random happenstance but instead stem from failures of preparation and procedure. Accordingly, among those interested in mitigating risk, there is often a wholesale rejection of Taleb’s thesis that Black Swans are predictable only in retrospect (e.g., Cooper & Eschleman, 2021; Flage & Aven, 2015; Hajikazemi et al. 2016; Piore, 2011). In fact, some have argued that preventing Black Swans involves first rejecting the notion that Black Swans are unpreventable, as this line of thinking is counterproductive to threat detection and ignores the proven success of mitigation efforts (Krausmann & Necci, 2021; Murphy & Conner, 2012). Accordingly, the strategies proposed by these experts primarily involve enhancing knowledge and preparedness, identifying vulnerabilities, and responding to warning signs. However, a few commentaries have followed more closely from Taleb’s (2010) original position, suggesting that the most rational and efficient course of action is to shift

attention away from futile efforts of prediction and prevention and instead work to minimize the harmful consequences of Black Swans (Nafday, 2009; Wardman & Mythen, 2016).

### ***Transforming “Unknowns” into “Knowns”***

Although Black Swans are often described as “unknown unknowns,” risk management experts are sometimes dismissive of fatalistic notions that Black Swan events are fundamentally “unknowable” (Cooper & Eschleman, 2021; Murphy & Conner, 2012). Aven and Krohn (2014), for example, have chosen to expand the definition of Black Swans to include plausible future events that have negligible probability as well as “unknowns” that may become knowable (see also Aven, 2015; Paté-Cornell, 2012). Because ignoring Black Swans entirely is an untenable position given the potential for extreme and catastrophic consequences, risk management in the context of “unknown unknowns” necessarily involves first acknowledging that many Black Swans can be successfully prevented if appropriate steps are taken:

Black-Swan risks are not captured by standard probabilistic assessment models, requiring a broader risk perspective that transcends traditional engineering risk analysis and risk management practice. This is true for all types of unknown rare and extreme risks.

Realistically, we will never be able to fully access all Black-Swan risks, but with a change in mindset that fosters out-of-the-box thinking and improved assessment approaches, the surprise effect can be mitigated. (Krausmann & Necci, 2021, p. 9)

Beyond rejecting this “act-of-God” perspective and recognizing that effective risk management options are available even when knowledge is limited, commenters recommend relying on experts who may have esoteric knowledge (i.e., “unknown knowns”) that can effectively guide preparatory actions (Cooper & Eschleman, 2021). Red teaming and scenario planning also are invaluable strategies (Lyon & Popov, 2022; Masys, 2012), as they can help overcome the so-

called “failure of imagination”—vulnerabilities that a designer or regulator would not necessarily foresee (Piore, 2011). Finally, because “knowns” can become “unknown” due to time decay, reliance on storytelling rather than fact-based education can help key decision-makers avoid repeating the consequential past mistakes of others, thus ensuring that White Swans do not become Grey or Black Swans (Lindaas & Pettersen, 2016; Murphy & Conner, 2014).

### ***Identifying Vulnerabilities and Warning Signs***

As mentioned above, there are plentiful examples of disastrous events widely considered to be Black Swans that were forecasted in light of existing evidence (Ale et al., 2020; Lyon & Popov, 2022; Runde, 2009). Indeed, while few decisions are made with absolute certainty, it is crucial to take note of “emerging risks,” that is, “risk related to an activity when the background knowledge is weak but contains indications/justified beliefs that a new type of event...could occur in the future and potentially have severe consequences to something humans value” (Flage & Aven, 2015, p. 66). While Black Swans themselves could be harbingers of future events rather than mere aberrations (Mueller & Stewart, 2016), Black Swans also may be precipitated by early warning signs that can go overlooked (Aven, 2015; Hajikazemi et al., 2016; Masys, 2012). Effectively identifying and responding to these “imprecise early indications about impending impactful events” (Ansoff & McDonnell, 1990, p. 20) requires honest reflection on the potential weaknesses of a system (Cooper & Eschleman, 2021). To aid in this endeavor, some experts have devised metrics through which such vulnerabilities may be measured (Gray & Alles, 2021; Zarghami & Dumrak, 2021); the use of such tools may be insightful.

### ***Mitigating Consequences***

Finally, a central problem surrounding recommendations to transform “unknowns” into “knowns” based on prior experience, imagination, and early warning signs is that “invisible and

complex outcome generators might produce different outcomes in the future than they did in the past” (Blyth, 2009, p. 450). Black Swans are, by definition, unobservable based on existing data, and thus risk mitigation efforts designed to prevent events that have never occurred and may never occur very often have benefits that are opaque (Aven, 2013; Lindaas & Pettersen, 2016). Given these problems that are fundamental to Black Swans, some commenters have argued in favor of directing attention not toward prevention but rather toward controlling the negative consequences of Black Swans (Nafday, 2009). Relevant issues in this regard involve considering how other nations respond to Black Swans in order to improve systems domestically (Woodall et al., 2024) as well as improving communication with the public about risk and precautionary logic (Wardman & Mythen, 2016). As Taleb (2010) himself states, “There is no such thing as Black Swan proof, but robust is good enough” (p. 374).

### **Conclusion**

For the professionals tasked with protecting interconnected critical infrastructure systems, Black Swans represent more than just a thought experiment. Predicting all catastrophic events is impossible, yet diligent experts sometimes can observe evidence pointing to vulnerabilities that are actionable. The specific features of future terrorist attacks, natural disasters, and pandemics likely fall within the domain of “unknown unknowns,” but evidence and experience can still provide useful—albeit imperfect—guides to addressing risks that exist within a normal distribution of data points. Nonetheless, some Black Swans cannot be anticipated at all, and those who fall victim to the “narrative fallacy” may offer counterproductive explanations and inaccurate assessments of probability after the fact. As the above-described literature reveals, these considerations weigh heavily in risk management decision-making, as extreme rarity must be reconciled against incalculable costs.

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