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Swans and elephants: A typology to capture the challenges of food supply chain risk assessment

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ABSTRACT

Background: As a result of internal or external shocks, food supply chains can transition between existing regimes of assembly and planned activity to situations that are unexpected or unknown. These events can occur without warning, causing stress, shift, even collapse, and impact on business/supply chain viability.

Scope and Approach: The aim of this research is to consider how with existing complexity, uncertainty and constantly emerging transitions, risk managers food supply chains can comprehend, and address risk. This study, based on an iterative analysis of grey and academic literature, considers the application of multiple swan (black, grey, white) and black and white elephant theory to food supply chain risk. Case study examples explore and explain the academic theory in more depth. Five types of risk are considered: known knowns, unknown knowns, known unknowns, unknown unknowns and a category introduced in this paper, unknowable unknowns.

Key findings and conclusions: Traditional risk assessment techniques, mediated by the level of knowledge uncertainty, lead risk managers to accept, tolerate, treat or ignore a risk. Effective risk assessment can convert black swans via grey swans ultimately into white swans, but in some circumstances, white swans can escalate to be grey swans again. When the risk manager intentionally chooses to accept a black elephant, this can result in a significant public health incident and/or extreme financial impact. The multiple swan (black, grey, white) and black and white elephant typology developed here can assist risk managers to more effectively visualise and rank supply chain risk.

Introduction

Supply chain risk can lead to shocks, either internal or external to the business or wider food supply. These shocks can lead to a single event or a combination of events that cause transition between existing regimes of assembly and planned activities to situations that are unexpected, or even unknown. If the resultant impacts are extreme, they will cause economic and/or personal harm and loss. These events occur because of the reshaping of interactions between existing structures, actors, processes and systems that operate at many different levels but are vulnerable to shift, reconfiguration, change and even in extreme circumstances to collapse (Li, Li, Kappas, & Pavao-Zuckerman, 2018; Markard, Raven, & Truffer, 2012; Rauschmayer, Bauler, & Schäpke, 2015; Sornette, 2009). It is within this framing that stakeholders determine risk, individually at the business level or, in consort at the supply chain level, and as a result, risk identification, assessment and management systems are developed and implemented.

Risk assessment in the context of scientific uncertainties, and potentially extreme consequences is problematic as poor knowledge (or a lack of data or unreliable data) can lead to over simplification, a lack of consensus, a lack of understanding and ultimately a failure to develop valid, representative and effective predictive risk models (Aven, 2013). In the instance of a low probability and a high consequence event, there is even uncertainty about how the degree of probability of an event can even be determined, and this particular situation (low probability/high risk) is where risk assessment becomes especially difficult (Paté-Cornell, 2012Paté-Cornell, 2012). Whilst severe events e.g. complete crop failure in a given region, or human disease outbreaks such as COVID-19, can have a significant economic, environmental and social impact, they are often outliers (Sornette, 2002), so it can be difficult to predict the probability of such natural, socio-political, human health or

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environmental events and they do not effect individuals, organisations or communities equally (Neumeyer & Plümper, 2007). Indeed, based on existing assumptions or beliefs, risk managers undertaking a risk assessment may simply ignore a risk event, either classifying it as an outlier, or deeming it very unlikely or the impact as negligible and thus not worthy of consideration (Aven & Krohn, 2014). Therefore, low probability and high risk events share "characteristic nonlinear behaviours that are often generated by cross-scale interactions and feedbacks among system elements [i.e. they are instances of complexity]. These events result in surprises that cannot easily be predicted based on information obtained at a single scale" (Peters et al., 2004, p. 15130). These surprises have been termed in the literature as "black swans".

A black swan is an "unknown" where its very existence is not recognised or predicted. Black swans are "future circumstances, events or outcomes that are impossible to predict, plan for, or even to know where or when to look for them" (Gleadale, 2011, p.10). The concept of "unknown unknowns" i.e. risks that are specifically deemed unknown or unknowable, and unpredictable are often described in light of the Donald Rumsfeld speech in 2002 when speaking about evidence based decision-making:

"Reports that say that something hasn't happened are always interesting to me, because as we know, there are known knowns; there are things we know we know. We also know there are known unknowns; that is to say we know there are some things we do not know. But there are also unknown unknowns – the ones we don't know we don't know (Logan, 2009)."

The concept of unknown unknowns is widely discussed in contemporary academic literature associated with risk (Taleb, 2007; Aven, 2013, 2015; Aven & Krohn, 2014; Dufva & Ahlqvist, 2015; Flage & Aven, 2015; Hajikazemi, Ekambaram, Andersen, & Zidane, 2016; Wardman & Mythen, 2016). However, more recently it has been associated with food related policy (Manning & Soon, 2014). The United Kingdom (UK) Food Standards Agency (FSA) describe "unknown unknowns" as: "future circumstances, events or outcomes that are impossible to predict, plan for, or even to know where or when to look for them." (Gleadale, 2011, p. 10). Marshall, Ojiako, Wang, Lin, and Chipulu (2019) highlight four different types of risk (Table 1) namely known knowns, unknown knowns, known unknowns and unknown unknowns. Maes (2016, pp. 1–17) differentiates here between unknown unknowns and unknowable unknowns in that the former are risks we "do not know," and the latter are risks "we could never know." Regulatory bodies and the food industry itself require clarity on the need to balance existing risk assessment activities for determining known knowns, known unknowns, unknown knowns with variable levels of efficacy and also seek to quantify or qualify the risk of an unknown or an unknowable unknown occurring. One of the critical objectives of the earlier stages of the risk management process in the food supply chain is to seek to address unknown unknowns so that they are included holistically, if not specifically, in an effective risk management system. However, there will always be some "unknowable unknowns" i.e. events that will always lie outside any risk management approach.

Table 1
Five states of risk forecasting knowledge (Adapted from Marshall et al., 2019).

State	Description
Known knowns	Risk is known both abstractly (in correspondence to events which do or may happen) and as a concrete risk exposure whose portent or impacts can be described using available evidence.
Known unknowns	It is understood that a particular type or category of risk deserving attention, yet there is lack of convincing evidence for its presence as a concrete risk exposure for the organisation at a particular time.
Unknown knowns	Risk is less well known abstractly, but individual or organisational experience of it nonetheless necessitates its management.
Unknown unknowns	Possible risks which have not been imagined/conceptualised and evidence for whose relevance within some specific organisational context might exist embryonically as scattered information, but not as coherent risk knowledge.
Unknowable unknowns	Possible risks which we could never know and only with hindsight could we suggest that they might have been knowable.

A "black elephant" event is a known, high-impact, high consequence, even catastrophic event that lies beyond the realm of regular expectations, but is purposefully ignored in the risk assessment process by risk managers despite evidence of its existence and as a result is distinctly different from a "black swan" event (Möller & Wikman-Svahn, 2011). When the risk manager intentionally chooses to accept a black elephant, this can result in a significant public health incident and/or extreme financial impact on the business and wider supply chain.

The aim of this research is to consider how with existing complexity, uncertainty and constantly emerging transitions, risk managers in food supply chains can comprehend, and address risk. This study, based on an iterative analysis of grey and academic literature, considers the application of multiple swan (black, grey, white) and black and white elephant theory to food supply chain risk. Case study examples explore and explain the academic theory in more depth. Five types of risk are considered: known knowns, unknown knowns, known unknowns, unknown unknowns and a further category introduced in this paper, unknowable unknowns. This consideration of unknowable unknowns is considered to be particularly novel in this paper. This category of risk that is added to Table 1 unknowable unknowns are the possible risks, which we could never know and only with hindsight could we suggest that they might have been knowable. The development of a multiple swan (black, grey, white) and black and white elephant typology will assist risk managers to more effectively visualise and rank supply chain risk.

The approach employed in this study was to firstly review of existing literature to frame the conceptual swan and elephant typology in the context of risk identification, assessment and management in the food supply chains. An iterative, snowball review approach was used where initial sources provided context and highlighted key aspects of risk consideration which then informed further searches of the literature. Key terms used in this review included: risk management AND risk assessment AND supply chain risk AND black swan AND black elephant AND white elephant AND grey swan AND white swan AND horizon scanning AND sense making. A research proposition is postulated and considered in this study:

Proposition. A risk typology based on swans (black, grey, white) and black and white elephants is of value to risk managers in the food supply chain.

Case study examples are used throughout this paper to explore the academic theory and contemporary evidence in more depth.

2. Literature review

Food safety risk is described as "a function of the probability of an adverse health effect, and the severity of that effect, consequential to a hazard(s) in food" (European Commission (EC), 1997). More widely, supply chain risk is "an event that adversely affects supply chain operations and hence its desired performance measures, such as chain-wide service levels and responsiveness, as well as cost" (Tummala & Schoenherr, 2011, p. 474). Borghesi and Gaudenzi (2013) considered four types of risk; market risk, process risk, supplier risk and environmental risk as well as the risks associated with transparency and information visibility. A risk register is a central tool for identifying known supply chain risks and creating a risk profile for a given organisation that can be updated as situations change (Whipple & Pitblado, 2010; Leva, Balfe, McAleer, & Rocke, 2017). An organisation within its annual report will often include a risk register of all business and supply chain risk. This is considered now in a case study.

2.1. United Kingdom (UK) retailer risk registers

Three recent retailer risk registers are considered here. In the Tesco plc Annual Report and Financial Statement (2020) the principal risks are recorded and annotated as to whether the risk is believed to be increasing, decreasing, a new risk or there is no movement in the level of risk. The principal risks can be categorised as reflecting value proposition and value delivery (customer, brand, reputation and trust); value delivery (transformation); resilience (liquidity, technology, competition and markets, people (capability), Brexit, COVID-19, Tesco Bank); and compliance (data security and data privacy, political, regulatory and compliance, health and safety, and responsible sourcing and supply chain). Of note in this risk register only responsible sourcing and supply chain mentions "food" explicitly. UK retailer J Sainsbury plc uses the same principal risk approach in its Annual Report 2020, but describes its individual principal risks differently, only including the word "food" once in its risk register and then only in connection with food waste. Morrisons plc Annual Report and Financial Statements 2019/20 again follow the same approach and only mentions food in one principal risk and this is termed "food safety and product integrity." This presentation of risk in a formal register in financial reports is framed by the corporate disclosure required by regulation in the UK, but it is of interest to consider disclosed known supply chain risk and the wider context in which food safety and product integrity is considered and assessed by the three retailers analysed here.

Thus, a risk register, supported by a risk scoring matrix is a tool often used by organisations to identify and record the issues that pose the highest risk to a given business operation (Mace, Hails, Cryle, Harlow, & Clarke, 2015).

2.2. Risk assessment matrices

Risk matrices are traditionally used to assess risk in a variety of risk settings (food safety, food fraud and food defence), however they are mainly used to rank the risks to inform and prioritise decision-making based on a given known or predictable set of scenarios. The traditional risk matrix that focuses on two variables i.e. likelihood (occurrence) and severity of consequences (impact) lacks finesse resulting in poor operational performance (Luo, Wu, & Duan, 2018). The use of scoring e.g. low (1), medium (2), high (3) versus unlikely (1), likely (2), certain (3) can lead to a risk index (likelihood x severity) that is subjective and will only provide a rudimentary determination of perceived risk (Van der Fels-Klerx et al., 2018). The likelihood terms in risk matrices whilst sometimes using the descriptor "certain", actually interpret this as a likelihood very close to 100%, i.e. uncertainty is not fully excluded and the risks are merely perceived to be very likely. Likelihood is a qualitative or semi-quantitative term that is more abstract in terms of how it describes how likely something is to happen and is based on risk managers' judgment that can often be subjective (Manning, 2013). Marshall et al. (2019) differentiate risk forecasting in terms of an 'abstract' mindset, i.e. expressing theoretical imagination in terms of abstract categories and forms of risk and a more 'concrete' mindset that is data-driven and rooted in context-specific description. This differentiation highlights the difference between likelihood and probability. Probability is a mathematical determination of how likely an event is to occur i.e. it is a quantitative, concrete assessment, which may be stated within a specified confidence limit.

Several perspectives on risk have developed that replace the variable "probability" or "likelihood" with "uncertainty" as the "pure probability-based perspective on risk [is] too narrow, ignoring and concealing important aspects of risk and uncertainties" (Aven & Krohn, 2014, p. 1). Uncertainty reflects "a lack of clarity or quality of the scientific or technical data" (Todd, 2011, p. 1516). Aven and Krohn (2014) assert that whilst a given probability could be determined to be the same in two situations, the assumptions made and the strength of knowledge and the degree of uncertainty that is associated with that knowledge can be completely different in one situation compared to another. Therefore, determining risk based on probability could undermine the validity of such assessment. Zio (2016, p141) highlights the dangers of reducing risk assessment to a given number or value because:

"the values of probability in two different situations could be the same, but their assignment may be based on quite different knowledge, data and information, and eventually assumptions [or degrees of uncertainty], which leave quite different room for surprises of unforeseen events and related consequences."

Indeed the European Commission (EC) (2000) definition of risk assessment states that appraisal of exposure is determined by evaluating qualitatively or quantitatively the probability of exposure to a biological, chemical or physical agent that can cause an adverse event (Manning & Soon, 2013). Further, quantitative, semi-quantitative or qualitative risk assessment models for policy, finance or economics are often lacking in how they take account of the "entropy" of existing regimes and transition (Krupa & Jones, 2013). It has been suggested that this is the same in food supply chain risk assessment processes (Manning, 2013; Manning & Soon, 2013).

Fuzzy logic based risk assessment considers that a single variable can be a member of multiple groups e.g. it can capture uncertainty, vagueness and aggregated risk that if one event happens this then makes a second event more likely (Manning & Soon, 2013). Fuzzy logic approaches have been used to consider supply chain failure and the associated risk for products and processes (Ghadge, Fang, Dani, & Antony, 2017). Indeed, there is a body of research that has used failure, mode, and effect analysis (FMEA) to consider known risks, causes and potential factors of influence in order to develop risk treatment and risk management activities (Ghadge et al., 2017; Giannakis & Papadopoulos, 2016; Wu & Hsiao, 2020). Fuzzy logic, linked to FMEA as an approach flows from seeking to address the challenge of complexity. However, this approach is of limited value when considering unknown or unknowable risks.

2.3. Risk management

Traditional methods of risk management such as standards development and verification through third party auditing are ineffective against unknown or unknowable, unknowns (Manning & Soon, 2014) i.e. there is a failure herein to apply the precautionary principle associated with food safety management in this situation (Schoenherr, Narasimhan, & Bandyopadhyay, 2015). Manning, Luning, and Wallace (2019) citing incidents such as fipronil in eggs and egg based food products highlight that if hazards are unknown by risk assessment teams (in this case using a hazard analysis critical control point or HACCP approach), then potential hazards and their associated risk will "simply go under the radar." Concern with regard to unknown unknowns and best practice in undertaking risk assessment processes to develop a risk management process for food adulteration particularly focuses on this challenge (Chen, Zhang, & Delaurentis, 2014; Manning & Soon, 2014). It is important to recognise that not only can risk managers' knowledge of the risk change over time, but the risk itself could change for example a virus could transform from a low pathogenicity to a high pathogenicity strain, invalidating previous risk assessment decisions. This process of invalidation is not because the risk assessments were invalid at that previous point in time, but that the assessments over time become out of date, perhaps dangerously so. This is a key factor to consider in long term risk management processes. Todd (2011) differentiates between simple, complex, uncertain and ambiguous types of risk. Risks can be:

"1) [simple] routine, mundane; 2) complex and sophisticated with a high degree of modeling necessary; 3) highly uncertain because of lack of appropriate data; 4) highly ambiguous with a high degree of controversy; 5) imminent dangers or crises with a need for a fast responses)" (Todd, 2011, p. 1516).

However, it is important to note that these are not mutually exclusive categories, for example, a risk can be both routine and complex, highly

uncertain and an imminent danger or any other combination. The types of risk outlined here, the associated risk approach and the associated risk narrative have been synthesized (Table 2).

2.4. Take in Table 2

Multiple risks can come together in a non-linear, complex event to produce an accumulated risk that is greater than the individual risks would have been had they occurred independently. This type of incident is a "perfect storm" (Paté-Cornell, 2012). A "perfect storm" is a combination of uncertainty, and aggregated "risky" events with singular and multiple negative outcomes occurring simultaneously. Therefore, whilst the multiple combination of probabilities for potential scenarios of different concurrent events can be determined, or at least a judgemental assessment of likelihood made, the level of dependency and interdependency between variables of influence and events and their probability must also be known to assess the impact of this combination of conditions (Paté-Cornell, 2012). This makes management of risk difficult, as does the challenge of emerging risk that was not considered in the previous risk assessment process. Emerging risk i.e. newly created risk, newly identified, known or observed risk, or a risk that has an increasing level of riskiness over time will be identified recognised and then established in risk assessment and management processes by risk managers (Flage & Aven, 2015). However, emergent risk can be associated with high levels of uncertainty that as a result makes both risk assessment and risk management difficult. The next section of the paper considers whether a risk typology based on swans (black, grey, white) and black and white elephants is of value to risk managers in the food supply chain.

Table 2
Types of risk, risk approach and risk narratives (Adapted from Todd, 2011).

Types of risk	Approach	Narrative
Simple risks	Routinely managed via introduction of legislation or controls by businesses or the wider market. Examples include traceability legislation, legislation associated with allergen control. Simple controls to reduce food safety risk include pasteurisation, freezing, chilling etc.	The science says the risk is real but some stakeholders can see the individual risks as uncertain or ambiguous.
Complex risks	Complex risk problems are associated with major scientific disagreement about complex dose-effect relationships or the effectiveness of risk mitigation and vulnerability reducing measures.	Scientific characterisation is via the use of evidence to access and develop risk mitigation measures. Narrative uses terms such as a 'risk-informed' and 'robustness' assessment.
Uncertain risks	Risks about which there is a knowledge deficit and multiple unknowns. Examples of uncertain risks include black swans, natural disasters, intentional adulteration, and risks that may have long term impacts which are not realised within the timescales of product approvals.	Often in this context, there are multiple narratives with limited knowledge and uncertainties so the precautionary principle may be used.
Ambiguous risks	Risks that may be tolerated by some stakeholders and not others. Some stakeholders may follow an objective approach, whilst others use a subjective approach to determine risk.	There are contested perspectives on the justification, impact and meanings associated with a given agent or threat. Narratives by some stakeholders may exclude the views of others creating opacity, inertia and indecision.
Imminent danger risks	Risks and crises where there is an imminent public health wider risk.	The narrative can include notions of fear and dread.

3. Black, grey and white swans and black and white elephants

Black swan theory (BST) was first explored by Taleb (Aven, 2013; Krupa & Jones, 2013) and has been applied to the energy sector (Krupa & Jones, 2013); finance (Bogle, 2008); and nuclear safety (Möller & Wikman-Svahn, 2011). As stated previously, a black swan is an unknown or unknowable unknown risk where its very existence is neither recognised, nor predicted/predictable by risk managers. In contrast, white swans are risks that are knowable, assessable and can be mitigated for, even eliminated. A black swan is said to be unforeseeable (Aven & Krohn, 2014). A black swan event has three attributes (Taleb, 2007). Firstly, a black swan is an outlier and nothing in the past can convincingly point to its possibility (*rarity*) and secondly, it has the potential to have a catastrophic impact (Aven, 2013; Bogle, 2008; Chichilnisky, 2010) i.e. *extremeness*. Finally, retrospectively human nature (hindsight) creates a narrative or explanation for the occurrence of a "black swan event", and by doing so individuals may seek to make the event appear explainable and predictable (Aven, 2013; Bogle, 2008; Krupa & Jones, 2013) i.e. to provide a *retrospective predictability*. Retrospective predictability makes the unknown even the unknowable in hindsight, become recast as being knowable. These false "rear-view" narratives appear to be plausible explanations of how disordered events unfolded (Krupa & Jones, 2013); seek to make sense of complexity and can drive the data to tell the story "we want to tell" rather than describe what actually happened (Blyth, 2009). This type of behaviour could be linked to concern over a litigious blame culture. Thus, a black swan can be firstly, a rare event with extreme consequences i.e. an extreme event that is deemed "unlikely" with the present level of knowledge or information, or because such information is incomplete, partial, absent or contingent (Aven, 2013; Wardman & Mythen, 2016). Knowledge can also be differentiated from being shallow knowledge i.e. systems, standards, procedures, protocols or methods) and deep knowledge i.e. perceptions, beliefs, emotions or culture (Klammer & Gueldenberg, 2019). Secondly, a black swan event can result from the non-occurrence of an event that is regarded by risk assessors as being highly probable to occur (Bogle, 2008); or the result of a failure in a crucial control that is always expected to operate. Examples of black swan events at the system and organisational level have been collated (Table 3).

3.1. Take in Table 3

Hajikazemi et al. (2016) state that not all severe incidents are black swans, rather that a black swan is specifically a "game-changer" event for those who are impacted by it e.g. the Lehman Brothers bankruptcy in 2008 (Hajikazemi et al., 2016), or COVID-19 in 2020 (Ker & Cardwell, 2020). Others suggest that COVID-19 or rather a coronavirus outbreak on a global scale was actually predictable as coronaviruses are a known

Table 3
Examples of black swan events (adapted from Chichilnisky, 2010; Flage & Aven, 2015).

System level black swan events
Catastrophic climate change leading to system failure
Failure of critical infrastructure
Global warming
Natural hazard
Market crashes
Regime change in complex systems
Species extinction
Spread of infectious human disease such as COVID19 or animal or plant disease
Organisational level black swan events
Failure of critical control that is expressly enacted to mitigate or eliminate a risk
Failure of critical infrastructure or back-up system
Incident associated with unknown or unknowable internal organisational risk
Unexpected data loss or data system failure

risk and thus this event is not a black swan (Inayatullah, 2020). Spink (2013) suggests that enterprise risk management approaches are of value in addressing black swans. Others argue that evidence-based approaches to determine risk are of little value when considering "black swan" events (Wardman & Mythen, 2016) as black swans often "lurk beyond the horizon" (Bogle, 2008). Therefore predictive risk assessment tools such as HACCP, threat analysis critical control point (TACCP), and vulnerability analysis critical control point, (VACCP) have limited efficacy in assessing and mitigating unknown or unquantifiable risk creating the potential for supply chain vulnerabilities to be both unknowable and unrecognised (Manning, 2019). A case study is now considered.

3.2. Black swan event – emergent zoonoses

Zoonoses are diseases or infections are transmitted from animals to humans or vice versa usually as a result of eating products of animal origin or direct contact with an infected animal. Some zoonoses' very existence is neither recognised as known or knowable in the timescale that it can be predicted and mitigated by risk managers as part of the risk appraisal and risk management process. An example of a black swan event linked to the food chain where there is a knowledge gap, or lack of evidence base which has then impacted on the ability to identify, quantify and manage risk is bovine spongiform encephalopathy (BSE). In 1986 the first diagnosis of an emerging disease in cattle in the UK, became understood to be BSE, leading to a period of uncertainty until BSE was made a notifiable disease in Britain two years later. In March 1996, British physicians reported 10 cases of new variant Creutzfeldt-Jakob disease in humans i.e. an emergent public health issue (Dormont, 2002; Will et al., 1996). This accelerated concern. Todd (2011) defines BSE as a black swan event where initially and through the crisis, different stakeholders have conflicting views on the event, signals of a risk become known, but the scope of the risk is seen (falsely) as being local rather than broader in terms of impact. There is also no awareness by risk managers of the risk itself and its impact. In this context scope of the risk could be localised geographically i.e. at the county, country, regional or global scale and equally as an animal disease rather than both an animal disease and a public health issue for the human population as the agent has the potential to jump the species barrier.

This example suggests that a black swan event in itself can be a tipping-point i.e. after the event has occurred the food regime transitions to another state and does not return. As a result of BSE, regulatory and market changes occurred with regard to products of animal origin in Europe which remain in place today. Another type of black swan event is when a control on which the farmer, manufacturer or retailer depends suddenly and unexpectedly fails. This can be due to a single issue such as system overload, component failure or it can be a wider multiple system failure. Examples include the failure of a critical control e.g. heat process, chilling process that is expressly enacted to mitigate or eliminate a risk and associated fail-safe system simultaneously; or the failure of critical infrastructure or digital system failure (Table 3). The risk of failure can be muted within a business or alternatively in a wider collective narrative it can assert that systems simply "cannot fail," that there is no need for contingency, and that there is no need for redundancy within the process or systems.

3.3. Resilience and redundancy

Resilience is a key aspect of risk management and mitigating processes through reducing supply chain brittleness and risk of system failure whilst also promoting buffer capacity and adaptive capacity. Driving supply chain efficiency through a "just-in-time" approach reduces the cost of stock holding, and transaction costs through better self-organisations (assembly, disassembly and reassembly), but as a result can eliminate buffer capacity and redundancy. Sustainable food supply chains must be resilient, resistant (can withstand shocks) and have redundancy i.e. a clear continuity plan (Ikerd, 2011). Indeed resilient system design that aims to reduce disruption risk must encompass redundancy and optimise continuity planning (Pavlov, Ivanov, Pavlov, & Slinko, 2019). Designing resilient supply chains requires a trade-off between resilience, leanness and redundancy where different risk scenarios are mapped to determine alternative strategies and redundancy systems (Stewart & Ivanov, 2019). Flexibility approaches can be developed to address supply risk, delivery risk and manufacturing process risk and reduce disruption (Carbonara & Pellegrino, 2017; Kamalahmadi & Mellat-Parast, 2016; Shekarian, Nooraie, & Parast, 2020; Sreedevi & Saranga, 2017). Sheffi and Rice (2005) suggest flexibility is more important than redundancy, while Gružauskas and Vilkas (2017) observe that flexibility and redundancy are both required and organisations should focus on integration capacity, reducing complexity and considering opportunities for collaboration to improve resilience. This interaction of flexibility and redundancy and how they can promote supply chain robustness and agility is worthy of further consideration (Simchi-Levi, Wang, & Wei, 2018; Mackay, Munoz, & Pepper, 2019). Therefore, in the clear knowledge that a black swan event will occur at some point in time, although its innate characteristics may be unknown to risk managers beforehand, networks can be developed based on strategic collaboration to share resources, and information and improve supply chain robustness (Gružauskas & Vilkas, 2017). Redundancy has two aspects: anticipation of unexpected disruptive events and preparedness should those events occur (Gružauskas & Vilkas, 2017). Hodbod and Eakin (2015) observe that functional redundancy, an ecological term, drives enhanced response diversity and this lies at the heart of resilience. In this context, functional redundancy suggests that where processes perform similar roles in systems they may be substitutable with little impact on the system outcomes (Rosenfeld, 2002). Loreau (2004) describes functional complementarity, which advocates resource partitioning so that different processes can operate both exclusively and interdependently. This terminology has not been applied in the context of food supply chains and food security but is worthy of more conceptual consideration in the future.

In summary, to address black swan events effectively, holistic risk management processes are needed to ensure functional, organisational and technological redundancy elements are in place in food systems. These approaches may be a combination of contingency elements such as additional devices, people, space or information systems that can be activated if a black swan event occurs, and based on the event and the system failures that subsequently arise, either singularly or in an iterative combination (Jacyna-Gołda & Lewczuk, 2017). The elements of the three types of redundancy that are described here have been drawn together (Table 4).

Once a black swan is known, for example the harmful impact of BSE and vCJD, the risk will be included as part of wider supply chain risk assessments and mitigation strategies to safeguard public health will be adopted. This means that in terms of risk assessment the black swan becomes a grey swan and ultimately could become a white swan if the risk is completely eliminated. Indeed, the challenge for risk managers is to convert black swans into grey swans and prevent white swans from becoming grey swans again in the future (Murphy & Conner, 2014). However, redundancy measures need to always be adopted in case another black swan event occurs in the future. In order to reduce the risk of vulnerability to black swans there needs to be a refocussing from risk reduction associated with the knowable to uncertainty reduction linked to the unknown or the unknowable (Möller & Wikman-Svahn, 2011). A vulnerability assessment approach rather than a risk assessment approach is required that also reflects that inequalities in exposure and sensitivity to risk and unequal access to resources, capabilities, and opportunities systematically disadvantage certain individuals or organisations over others (Neumeyer & Plümper, 2007; Manning & Soon. 2019). Grey swans are now considered in more detail.

Table 4
Types of redundancy (Adapted from Jacyna-Gołda & Lewczuk, 2017).

Type of redundancy	Function	Elements of redundancy	Disadvantage
Functional redundancy	Potential for functional reconfiguring of the system to allow its adaptation. (flexibility, universalism)	**Pre-shock** Selection of universal equipment which may be moved between tasks. **Post and during shock** Adaption through the use of pivoting processes to allow reconfiguration of activities and stopping of certain activities so functions can be used to better effect elsewhere.	Some customers may be prioritised over and above others. This could cause long term issues for the organisation. Focusing may occur here within a wider resilience context of universalism. There may be a trade-off between functional redundancy and flexibility.
Organisational redundancy	Organisational tasks are oriented to maximise the utilisation of time and resources combining with technical modifications to increase productivity. (flexibility)	**Pre-shock** Adoption of integrated management systems to improve flexibility and better time efficiency. Adoption of motivation programmes for employees to drive more engagement and productivity and flexibility in skillsets. **Post and during shock** Ability to extend shifts to drive more production or offset shocks. Adoption of methods directing the flow of materials to and from a given location to reduce the work intensity of the process, in the function of costs of task implementation and availability of resources.	There may be a trade-off between costs and enabling flexibility.
Technological redundancy	Enhancing the dependability characteristics of the system through oversizing i.e. an overcapacity in efficiency. (Universalism, flexibility)	**Pre-shock, during and post shock** Increasing the capacity of functional areas (especially storage).Increasing the number of people and equipment. Using equipment and systems more efficiently.	Oversizing to exceed actual resource requirements causes a high unit cost. Universalism instead of focusing of resources may cause a drop in competitiveness.

3.4. Grey swans

Grey swan events are deemed very unlikely, but may have occurred in the past, to the same organisation, supply chain or industry, and thus potentially can be predicted by risk analysis processes (Akkermans & Van Wassenhove, 2018). It is worthy of note that particular attention needs to be paid to grey swan events, because even though they may not have been particularly catastrophic in the past, there is a risk of an organisation not learning from their occurrence nor improving supply chain processes as a result of their impacts and not being prepared should they arise again. Grey swan events are "high-consequence events that are unobserved and unanticipated [that] may nevertheless be predictable (although perhaps with large uncertainty)" (Lin & Emanuel, 2016). Further they argue that grey swans can be foreseen and planned for. Managerial preparedness in this context is a factor of two cognitive processes: firstly, learning from failure and then secondly, preventing a managerial forgetting loop (Akkermans & Van Wassenhove, 2018). Intentional knowledge loss and managerial forgetting are overarching terms to describe processes through which knowledge is lost in organisations or supply chains (Klammer & Gueldenberg, 2019). Indeed, they propose that

> "Just like organisational learning can be accomplished through knowledge generation, knowledge acquisition or knowledge transfer, unlearning can be achieved by means of knowledge extinction, interference, inhibition or suppression." (Klammer & Gueldenberg, 2019, p. 861).

There are advantages to intentional organisational forgetfulness e.g. forgetting knowledge that would increase costs and thus reduce competitive advantage or by losing outdated organisational knowledge emerging best practice can be improved, but there is a danger too in the unlearning process when crucial individuals leave an organisation and their knowledge is not sufficiently captured (Klammer & Gueldenberg, 2019). Deeply embedded knowledge can act as a barrier to new learning, innovation and adapting within the organisation, thus forgetting can be an intentional strategy to drive and implement change (de Holan & Phillips, 2004), the question this poses is whether unlearning is associated with grey swan events whereas intentional forgetting by an organisation can lead to benefits but also black elephants. A case study is now considered.

3.5. Grey swan event – presence of melamine in foodstuffs

The adulteration of food and feed materials with melamine is an example of a black swan event that has now become a grey swan. The use of melamine in protein containing foods to then give a false result for protein levels would have been unknown in 2007 when dogs and cats first fell sick and died in the US as a result of adulteration of gluten (Suchý et al., 2009). In the following year more than 294,000 babies were sick in China with over 50,000 hospitalised and at least six deaths as a result of melamine adulteration of the milk used in formula milk products (Ingelfinger, 2008; Zhu, Huang, and Manning (2019). The presence of melamine in dairy products continues to be an issue across the world including Iran (Maleki, Nazari, Yousefi, Khosrokhavar, & Hosseini, 2018; Shakerian et al., 2018); Uruguay (García Londoño, Puñales, Reynoso, & Resnik, 2018); and the US (Zhu & Kannan, 2018). Thus it is now a known contemporary threat not just in the milk supply chain, but other supply chains too. Traditional risk assessment techniques lead to a decision to accept, tolerate, treat or ignore a risk. Risk treatment is considered here as the steps taken to further mitigate the risk by improving associated control systems

Akkermans and Van Wassenhove (2018) suggest a linear process when considering grey swans, such as melamine contamination, from setting and then monitoring early warning thresholds that signal the potential for the grey swan to be realised. So grey swans are known unknowns and in the case of melamine contamination the potential threat and its impact is understood but within the bounds of a degree of uncertainty as to whether the illegal activity will actually be realised. The risk manager therefore is faced with determining the degree of greyness or indeed whether there are adequate controls in place and

appropriate relationships in the supply chain to reduce the risk to a white swan. Black elephants can also be a concern when undertaking risk assessment.

3.6. Black and white elephants

A white elephant is the type of risk that despite having the potential to be costly, it is also difficult, if not impossible, to dispose of (Enria, Farkas, & Overby, 2016, p. 51). A "black elephant" event is a high-impact or high consequence event that we have knowledge of i.e. we know it could realistically occur but which we choose to leave out of the risk management process, perhaps for reasons of personal or professional embarrassment. A black elephant event is distinctly different to a black swan event as the black swan only becomes known or indeed knowable with hindsight (Möller & Wikman-Svahn, 2011). In the event of a supply chain shock or a food safety incident, the retrospective narrative is that a black elephant event is reframed, as a black swan event to seek to negate any responsibility that the risk manager concerned knew the risk could occur (Möller & Wikman-Svahn, 2011). Further in this scenario it could be asserted that they were not reasonably expected to know that a course of actions could lead to public health harm or significant economic loss e.g. in the event of a recall. Indeed, if the internal organisational narrative and discourse described incidents as "unexpected" or "unforeseeable", i.e. risk is not identified and as a result appropriate controls cannot be put in place, this reduces the potential for blame and culpability (Krzyzaniak, 2018). It is important to note here that risk identification and risk management processes cannot occur independently of the "diligence question" whether it was reasonable to expect someone to know of a risk or indeed that the facts were knowable when the risk assessment process occurred irrespective of whether the person chose to access the knowledge base. Thus stating in hindsight that an event was unforeseeable allows organisations, and the individuals that work for them, to apportion blame, and ignore "uncomfortable truths" about potential supply chain vulnerabilities, inadequacies in management systems, or innate production system design flaws (Krzyzaniak, 2018). Within an unforeseeable narrative blame can then not be placed either on the risk managers who designed and implemented the "foolproof" risk assessment system beforehand or on the individuals who followed the controls that were in place (Lau, 2009). This retrospective denial acts as a barrier to effective food safety governance as it can be argued that prevention was not an option (Krzyzaniak, 2018). The modern focus in food supply chains on assurance and prevention, or the predictability-preventability paradigm (Lau, 2009), is framed by "a grandiose technocratic rationalising dream of absolute control of the accidental" (Castel, 1991, p. 289). Indeed formal rationality, via foolproof methods (beforehand methodisation) such as the use of risk assessment protocols, replaces individual risk manager(s) ability to use their own discretion and judgment which are seen as being error filled and uncertain (Lau, 2009). Aspects of the unforeseeable narrative have been drawn together (Table 5).

Table 5
Aspects of the unforeseeable narrative (Adapted from Lau, 2009; Krzyzaniak, 2018).

Aspect	Example narratives
Beforehand methodisation (control, prevention, protocol, system)	"Controls could not have been put in place for what is unforeseeable." "This incident could have not been prevented."
Predictability	"The potential for failure could not have been seen." "Multiple failures at once was not imagined as a possibility"
Accident	"What is unforeseeable or unpredictable is an accident."
Negligence	"We did the best that we could in the circumstances"

In the case of black elephants, design defects and intentional or unintentional negligence, or a combination of the two by different actors, are a concern with regard to food safety and wider incidents (Lau, 2009).

3.7. Black elephant incidents: Peanut Corporation of America and Cadbury Schweppes

Salmonella is a known pathogen that can cause harm to individuals (Cavallaro et al., 2011) and lead to widespread food poisoning outbreaks. In the 2008 case of Peanut Corporation of America (PCA), brothers Stewart and Michael Parnell were indicted on 76 counts for knowingly shipping peanut butter that contained Salmonella and faced lengthy prison sentences, a definite black elephant because the brothers chose to ignore the information they had on Salmonella contamination, and the potential high consequence public health impact that could occur. (Bousquet, 2018; Leighton, 2016). The outbreak was in 47 States in the United States (US), 714 people fell ill, 166 people were hospitalised, and at least nine people died with 3918 products recalled by around 400 businesses (Leighton, 2016). The company officials knowingly placed contaminated product in the market place, some with false certificates of analysis in markets that were focused on vulnerable groups such as children or the elderly.

Carroll (2009) considers another black elephant event, the 2006 Cadbury Schweppes recall of seven of its branded products (UK and Ireland) due to the possible contamination with Salmonella Montevideo where the food company remained silent on possible contamination as "only minute traces of Salmonella [were] present". Cadbury reframed a policy of zero tolerance for Salmonella to use a test called Most Probable Number (MPN) test that assumed that a first positive test could be overridden by a second negative test (Ross, 2008). Motarjemi and Lelieveld (2014, pp. 1–20) position that although human error can be forgiven by consumers, and this goes for other stakeholders too, ignorance (not knowing), negligence and wilful disregard cannot. In both incidents, the same issue arose the silence of the organisation on a known risk, but a risk both organisations were willing to accept when they despatched product onto the market.

Duty of care is a legal obligation on individuals to exercise due care to prevent foreseeable harm for i.e. actors have not been careless in their execution of their responsibilities (Lau. 2009). Due diligence as a legal defence in this context is a much discussed concept. In the UK, the due diligence defence arose as a change to liability law associated with food products with the advent of the Food Safety Act in 1990 (Caswell, 1998). Holleran et al. (1999, p.672) stated that due diligence is a relative term requiring individuals and organisations to do everything reasonable "but not everything possible." It has been argued more recently that the requirement to exercise due diligence has driven complexity and the scale of risk assessment and risk management processes (Manning et al., 2019). Thus, what lies at the heart of demonstrating the implementation of reasonable precautions (beforehand methodisation) and exercising due diligence are three factors. Firstly, to have a reliable risk assessment and control system in place; secondly to exercise integrity in risk assessment and risk management and finally to be honest as to the degree of risk appetite and risk acceptance that either the risk manager(s) or wider risk organisation is prepared to take. Further sense making activities with a wider range of stakeholders need to be instigated to determine the potential risk and the need to upscale the level of control or mitigating action (Tsakalidis et al., 2019). This is especially important in the event that a white swan becomes a grey swan; the degree of greyness increases for a grey swan as risk increases; or to a black swan or if a black elephant emerges.

3.8. Horizon scanning as part of sense making

Horizon scanning is the first element of sense making Hahn, Preuss, Pinkse, and Figge (2014) propose three stages in sense making: managerial scanning, interpreting and then responding (Table 6). These

Table 6
Elements of sensemaking (Adapted from Barr & Huff, 1997; Hahn et al., 2014).

Phase	Description
Scanning phase	Scanning involves information gathering. Decision-makers then reduce the amount and complexity of information considering "relevance" which depending on the cognitive frame they hold they will notice different aspects of a situation, in turn leading to differences in their information processing and interpretation of the situation. This means that in some situations the scanning process may exclude information that contradicts such frames or make assumptions that fills in the knowledge gaps.
Interpretation phase	Interpretation is the determination of meaning from the evidence or information available. The culture of the organisation, its shared beliefs and values will influence the meaning that is derived.
Responding phase	The cognitive frame will also influence the response

elements are now considered in turn. The UK FSA describe horizon scanning as:

"*The systematic examination of global risks, threats, opportunities and likely future developments which may impact upon food safety and are at the margins of current thinking and planning. Examples include political, economic, social/cultural, technological, legal and environmental drivers*" (Gleadale, 2011, p. 8).

Horizon scanning is a systematic examination of future potential threats, their prioritisation and effective management (Roy et al., 2014); and thus has a role as an element of an early warning system (Soon, Manning, & Smith, 2019). Alternatively, horizon scanning is described as a forward-focused methodology applied to improve either institutional planning or policy making where the focus is on potential future situations, hazards or opportunities (Food and Agriculture Programme (FAO), 2013). This approach considers the existing information, evidence or intelligence that is available about products, processes and the wider supply chain as well as socio-economic factors that could influence future risk in order to effectively map potential threats and vulnerabilities, identify the potential for their occurrence and the means for their control. Thus, horizon scanning must be a continuous, dynamic, iterative formalised process, especially if it is to be of value in addressing grey swan and potentially in a holistic way, black swan events. Further, it must be reactive to changes in products, processes and activities within an organisation and across the wider supply chain. If the evidence base, risk ranking and risk status changes, horizon scanning assessments must be updated and recommunicated to all relevant stakeholders.

Scanning involves information gathering and the filtering of such information. What is deemed relevant information and what is excluded as irrelevant may be decided based on previous knowledge and learning, and assumptions made to fill knowledge gaps and the positive exclusion of information that contradicts such cognitive frames. However, this is mediated by the known, unknown, knowable and unknowable narrative expressed earlier in the paper. Knowing relates to knowledge. Knowledge, i.e. what is known or unknown or indeed knowable, interacts to form information and patterns that can "contribute texture and sharpness to forecasts of complex risks" (Marshall et al., 2019). Dufva and Ahlqvist (2015) created a typology of four types of knowledge: codified knowledge, articulated knowledge, embodied knowledge, and out-of-radar knowledge (Table 7). This differentiation is important here. In terms of risk assessment, codified knowledge is the knowledge that informs risk assessment that is generic, transferable and not context specific as opposed to articulated knowledge, which is fixed to a specific framing or context, or embodied knowledge, which is embodied in people and framed by their expertise, skills and competences (Dufva & Ahlqvist, 2015). In this respect, codified knowledge can become articulated knowledge. Out of radar knowledge is knowledge that seems irrelevant in the context, knowledge that is either ignored or outside the scope, but can give novel insight into an issue (Dufva & Ahlqvist, 2015).

The next element of sense making is interpretation. Interpretation is the determination of meaning from the evidence or information available. The culture of the organisation, its shared beliefs and values will influence the meaning that is derived as has been shown with previous black elephant and grey swan events and thus interpretation can be situational within a given organisation, supply chain or national setting. The cognitive framing will influence the risk response that is made, the final element considered here. Islam (2019) argues that there is an interplay between sense making and sense giving so in considering frames as a knowledge structure interpretation forms a key element of dissemination to inform action. Sense giving is an interpretative process that supports sense making through forms of communication that influence how others see an organisational reality (Gioia & Chittipeddi, 1991; Klein & Eckhaus, 2017). Bøhm and Njå (2017, p. 36) propose that there are three types of interruption that affect the sense making process: interruptions linked to the socio-cultural aspects of a given context; interruptions linked to the way language is used to discursively negotiate power and legitimacy, and lastly interruptions linked to how emotional and physiological aspects influence the sense making processes. Sense making is influenced too by the type of warning indicators or signals developed (Orozco-Fuentes et al., 2019) and whether there are inbuilt action thresholds (Corral et al., 2019); the quality of information received (Corral et al., 2019), and the speed of notification (Corral et al., 2019; Rortais, Belyaeva, Gemo, Van der Goot, & Linge, 2010). Effective managerial sense making requires managerial preparedness that then an event, incident or action informs an agile, timely and appropriate response. Sense making is the process of trying to understand novel, confusing or ambiguous issues or incidents occurring inside and outside the organisation (Klein & Eckhaus, 2017; Maitlis & Christianson, 2014). Sense making assists managers to reduce ambiguity and consider complex choices and is a collective, co-constituted narrative process whereby individuals in an organisation construct and interpret their social environment, individually or as a consensus activity (Islam, 2019; Weick, 1995). In summary, horizon scanning can initiate a sense making process that may identify black swan events, but allows for ongoing analysis of grey swans and white swans as part of a wider risk surveillance approach and can provide information about more concerning situations that could be termed black elephants. Risk assessment has evolved and also the potential tools and approaches that can be adopted in terms of the risk management response. These include wider information sharing and communication using technology across the supply chain (Haleem, Khan, & Khan, 2019; Kumar, Singh, & Modgil, 2020). Emergent in this field is the use of internet of things (IoT) technologies

Table 7
Typology of knowledge (Adapted from Dufva & Ahlqvist, 2015).

Type of knowledge	Description	Forms/expression of knowledge
Articulated knowledge	Knowledge that is expressed in and explicitly fixed to a framing or context. Positioned between codified and embodied knowledge. Articulated knowledge is more open to misinterpretation.	Narratives that position knowledge explicitly in a given context.
Codified knowledge	Knowledge that is generic and not context dependent. Knowledge that is often understood based on previous concepts and is transferable. Sticky knowledge that is dependent on common codes and contexts.	Documents, papers, databases, recommendations for action.
Embodied knowledge	Knowledge that is embodied by people and framed by their skills, competences, understanding, experiences and expertise	Actions, intuition.
Out-of-radar knowledge	Knowledge that seems irrelevant in the context, knowledge that is ignored or outside the scope, but can give novel insight.	Wild cards, weak signals, free associations.

and artificial intelligence approaches and bespoke algorithms to better improve signal surveillance processes in the food supply chain.

4. Concluding thoughts

Food security is built on the resilience of the risk control system in a given supply chain. The degree of resilience is mediated by buffer capacity and adaptive capacity and the degree of redundancy built into the system. The risk management system is developed, implemented and operationalised based upon consideration of the control required to prevent single or multiple point failures as well as wider prevention measures within the organisation and wider supply chain. These controls can be stand-alone, complementary and substitutable. The controls also need to be agile enough to address how risks can change over time either to become of less concern or to escalate based on a particular set of events. Transitions between existing regimes of assembly and planned activity to situations that are unexpected and often unknown will occur. These supply chain shocks can impact without warning, driving situations of stress, shift, even collapse. As a result such events can impact on food security and business/supply chain viability. A typology of risks is considered here and the characterisation as black, grey or white swans and white and black elephants and it is asserted that such a typology will assist risk managers to more effectively visualise and rank supply chain risk. The major concern here is the risks that are considered in hindsight to have been unknowable as unknowable unknowns are difficult to mitigate and may or may not be addressed by generic risk management controls. The limitation to this paper is that it provides a conceptual rather than an empirical exploration of the swan and elephant typology, but as a result of this research, the typology could be readily adopted in risk management approaches in a range of food supply chain settings.

If the efficacy of risk assessment and wider risk management at individual business or at supply chain level is going to be improved, risk managers must consider two specific dimensions. The first is the reliability of the risk assessment process that can convert black swans on appearance into grey swans and then white swans, with minimal disruption and risk to consumers and commerce. The second is to assure the integrity of the risk manager. The known risk that could have devastating consequences, as shown in the case studies in this paper, is when the risk manager intentionally and with full knowledge of the potential impact, chooses to accept a black elephant risk that could realistically result in either a significant public health incident and/or an extreme financial impact on the business and wider supply chain.

References

Akkermans, H. A., & Van Wassenhove, L. N. (2018). A dynamic model of managerial response to grey swan events in supply networks. *International Journal of Production Research, 56*(1–2), 10–21.

Aven, T. (2013). On the meaning of a black swan in a risk context. *Safety Science, 57*, 44–51.

Aven, T. (2015). Implications of black swans to the foundations and practice of risk assessment and management. *Reliability Engineering & System Safety, 134*, 83–91.

Aven, T., & Krohn, B. S. (2014). A new perspective on how to understand, assess and manage risk and the unforeseen. *Reliability Engineering & System Safety, 121*, 1–10.

Barr, P. S., & Huff, A. S. (1997). Seeing isn't believing: Understanding diversity in the timing of strategic response. *Journal of Management Studies, 34*(3), 337–370.

Blyth, M. (2009). Coping with the black swan: The unsettling world of Nassim Taleb. *Critical Review, 21*(4), 447–465.

Bogle, J. C. (2008). Black Monday and black swans. *Financial Analysts Journal, 64*(2), 30–40.

Bøhm, M., & Njå, O. (2017). Learning points from real incidents–learning from what?. *Book of abstracts*.

Borghesi, A., & Gaudenzi, B. (2013). *Risk management: How to assess, transfer and communicate critical risks*. Milan: Springer.

Bousquet, K. (2018). A meticulous food safety plan today avoids handcuffs tomorrow. *J. Food Law & Policy, 14*, 271–283.

Carbonara, N., & Pellegrino, R. (2017). How do supply chain risk management flexibility-driven strategies perform in mitigating supply disruption risks? *International Journal of Integrated Supply Management, 11*(4), 354–379.

Carroll, C. (2009). Defying a reputational crisis–cadbury's salmonella scare: Why are customers willing to forgive and forget? *Corporate Reputation Review, 12*(1), 64–82.

Castel, R. (1991). From dangerousness to risk. In B. Burchell, C. Gordon, & P. Miller (Eds.), *The foucault effect*. Chicago, IL: University of Chicago Press.

Caswell, J. A. (1998). Valuing the benefits and costs of improved food safety and nutrition. *The Australian Journal of Agricultural and Resource Economics, 42*(4), 409–424.

Cavallaro, E., Date, K., Medus, C., Meyer, S., Miller, B., Kim, C., et al. (2011). Salmonella typhimurium infections associated with peanut products. *New England Journal of Medicine, 365*(7), 601–610.

Chen, C., Zhang, J., & Delaurentis, T. (2014). Quality control in food supply chain management: An analytical model and case study of the adulterated milk incident in China. *International Journal of Production Economics, 152*, 188–199.

Chichilnisky, G. (2010). The foundations of statistics with black swans. *Mathematical Social Sciences, 59*(2), 184–192.

Corral, C., Berenguer, M., Sempere-Torres, D., Poletti, L., Silvestro, F., & Rebora, N. (2019). Comparison of two early warning systems for regional flash flood hazard forecasting. *Journal of Hydrology, 572*, 603–619.

Dormont, D. (2002). Prions, BSE and food. *International Journal of Food Microbiology, 78*(1–2), 181–189.

Dufva, M., & Ahlqvist, T. (2015). Knowledge creation dynamics in foresight: A knowledge typology and exploratory method to analyse foresight workshops. *Technological Forecasting and Social Change, 94*, 251–268.

Enria, A., Farkas, A., & Overby, L. J. (2016). Sovereign risk: Black swans and white elephants 16. *European Economy*, (1), 51–71.

European Commission (EC). (1997). *European commission scientific committee for food, brussels European commission 1997 (93/43*. EEC; expressed on 13 June 1997).

European Commission (EC). (2000). *Commission of the European communities brussels, 02.02.2000 COM (2000) 1 – communication from the commission on the precautionary principle*.

Flage, R., & Aven, T. (2015). Emerging risk–Conceptual definition and a relation to black swan type of events. *Reliability Engineering & System Safety, 144*, 61–67.

Food and Agriculture Programme (FAO). (2013). *Food safety and quality programme. Horizon scanning and foresight. An overview of approaches and possible applications in food safety* (emphasis on possible applications by FAO's Food Safety Program) Background paper 2 FAO Early Warning/Rapid Alert and Horizon Scanning Food Safety Technical Workshop. Available at: http://www.fao.org/3/a-i4061e.pdf. (Accessed 1 September 2019).

García Londoño, V. A., Puñales, M., Reynoso, M., & Resnik, S. (2018). Melamine contamination in milk powder in Uruguay. *Food Additives and Contaminants: Part B, 11*(1), 15–19.

Ghadge, A., Fang, X., Dani, S., & Antony, J. (2017). Supply chain risk assessment approach for process quality risks. *International Journal of Quality & Reliability Management, 34*(7), 940–954.

Giannakis, M., & Papadopoulos, T. (2016). Supply chain sustainability: A risk management approach. *International Journal of Production Economics, 171*, 455–470.

Gioia, D. A., & Chittipeddi, K. (1991). Sensemaking and sensegiving in strategic change initiation. *Strategic Management Journal, 12*(6), 433–448.

Gleadale, A. (2011). *The identification of future food risks*. Food Standards Agency Board Paper. 25th January 2011.

Gružauskas, V., & Vilkas, M. (2017). Managing capabilities for supply chain resilience through it integration. *Economics and Business, 31*(1), 30–43.

Hahn, T., Preuss, L., Pinkse, J., & Figge, F. (2014). Cognitive frames in corporate sustainability: Managerial sensemaking with paradoxical and business case frames. *Academy of Management Review, 39*(4), 463–487.

Hajikazemi, S., Ekambaram, A., Andersen, B., & Zidane, Y. J. (2016). The black swan–knowing the unknown in projects. *Procedia-Social and Behavioral Sciences, 226*, 184–192.

Haleem, A., Khan, S., & Khan, M. I. (2019). Traceability implementation in food supply chain: A grey-DEMATEL approach. *Information Processing in Agriculture, 6*(3), 335–348.

Hodbod, J., & Eakin, H. (2015). Adapting a social-ecological resilience framework for food systems. *Journal of Environmental and Social Sciences, 5*(3), 474–484.

de Holan, P. M., & Phillips, N. (2004). Organizational forgetting as strategy. *Strategic Organisation, 2*(4), 423–433.

Ikerd, J. (2011). The economic pamphleteer: Essential principles of sustainable food value chains. *Journal of Agriculture, Food Systems, and Community Development, 1*(4), 15–17.

Inayatullah, S. (2020). Neither A black swan nor A zombie apocalypse: The futures of A world with the covid-19 coronavirus. *Journal of Futures Studies*.

Ingelfinger, J. R. (2008). Melamine and the global implications of food contamination. *New England Journal of Medicine, 359*(26), 2745–2748.

Islam, S. (2019). *Business models and the managerial sensemaking process*. Accounting & Finance.

Jacyna-Gołda, I., & Lewczuk, K. (2017). The method of estimating dependability of supply chain elements on the base of technical and organizational redundancy of process. *Eksploatacja i Niezawodność, 19*.

Kamalahmadi, M., & Mellat-Parast, M. (2016). Developing a resilient supply chain through supplier flexibility and reliability assessment. *International Journal of Production Research, 54*(1), 302–321.

Ker, A. P., & Cardwell, R. (2020). Introduction to the special issue on COVID-19 and the Canadian agriculture and food sectors: Thoughts from the pandemic onset. *Canadian Journal of Agricultural Economics/Revue canadienne d'agroeconomie*.

Klammer, A., & Gueldenberg, S. (2019). Unlearning and forgetting in organizations: A systematic review of literature. *Journal of Knowledge Management, 23*(5), 860–888.

Klein, G., & Eckhaus, E. (2017). Sensemaking and sensegiving as predicting organizational crisis. *Risk Management, 19*(3), 225–244.

Krupa, J., & Jones, C. (2013). Black Swan Theory: Applications to energy market histories and technologies. *Energy Strategy Reviews, 1*(4), 286–290.
Krzyzaniak, S. A. C. (2018). *Determining the barriers to effective food safety governance in food manufacturing: A case study* (doctoral dissertation, university of portsmouth). Available at: https://ethos.bl.uk/OrderDetails.do?uin=uk.bl.ethos.765711.
Kumar, A., Singh, R. K., & Modgil, S. (2020). Exploring the relationship between ICT, SCM practices and organizational performance in agri-food supply chain. *Benchmarking: An International Journal*.
Lau, R. W. (2009). The contemporary culture of blame and the fetishization of the modernist mentality. *Current Sociology, 57*(5), 661–683.
Leighton, P. (2016). Mass salmonella poisoning by the Peanut Corporation of America: State-corporate crime involving food safety. *Critical Criminology, 24*(1), 75–91.
Leva, M. C., Balfe, N., McAleer, B., & Rocke, M. (2017). Risk registers: Structuring data collection to develop risk intelligence. *Safety Science, 100*, 143–156.
Li, Y., Li, Y., Kappas, M., & Pavao-Zuckerman, M. (2018). Identifying the key catastrophic variables of urban social-environmental resilience and early warning signal. *Environment International, 113*, 184–190.
Lin, N., & Emanuel, K. (2016). Grey swan tropical cyclones. *Nature Climate Change, 6*(1), 106–111.
Logan, D. C. (2009). Known knowns, known unknowns, unknown unknowns and the propagation of scientific enquiry. *Journal of Experimental Botany, 60*(3), 712–714.
Loreau, M. (2004). Does functional redundancy exist? *Oikos, 104*(3), 606–611.
Luo, T., Wu, C., & Duan, L. (2018). Fishbone diagram and risk matrix analysis method and its application in safety assessment of natural gas spherical tank. *Journal of Cleaner Production, 174*, 296–304.
Mace, G. M., Hails, R. S., Cryle, P., Harlow, J., & Clarke, S. J. (2015). Towards a risk register for natural capital. *Journal of Applied Ecology, 52*(3), 641–653.
Mackay, J., Munoz, A., & Pepper, M. (2019). Conceptualising redundancy and flexibility towards supply chain robustness and resilience. *Journal of Risk Research*, 1–21.
Maes, M. (2016). Unknowable unknowns and extremes-beyond-extremes in decision making: Myth, apology, or opportunity?. *International forum on engineering decision making*. 9th IFED Forum).
Maitlis, S., & Christianson, M. (2014). Sensemaking in organizations: Taking stock and moving forward. *The Academy of Management Annals, 8*(1), 57–125.
Maleki, J., Nazari, F., Yousefi, J., Khosrokhavar, R., & Hosseini, M. J. (2018). Determinations of melamine residue in infant formula brands available in Iran market using by HPLC method. *Iranian Journal of Pharmaceutical Research: International Journal of Psychological Research, 17*(2), 563.
Manning, L. (2013). Development of a food safety verification risk model. *British Food Journal, 115*(4), 575–589.
Manning, L. (2019). Food defence: Refining the taxonomy of food defence threats. *Trends in Food Science and Technology, 85*, 107–115.
Manning, L., Luning, P., & Wallace, C. A.((2019). The evolution and cultural framing of food safety management systems - where from and where next? *Comprehensive Reviews in Food Science, 18*, 1770–1792. https://doi.org/10.1111/1541-4337.12484
Manning, L., & Soon, J. M. (2013). Mechanisms for assessing food safety risk. *British Food Journal, 115*(3), 460–484.
Manning, L., & Soon, J. M. (2014). Developing systems to control food adulteration. *Food Policy, 49*(1), 23–32.
Manning, L., & Soon, J. M. (2019). Food fraud vulnerability assessment: Reliable data sources and effective assessment approaches. *Trends in Food Science & Technology, 91*, 159–168.
Markard, J., Raven, R., & Truffer, B. (2012). Sustainability transitions: An emerging field of research and its prospects. *Research Policy, 41*(6), 955–967.
Marshall, A., Ojiako, U., Wang, V., Lin, F., & Chipulu, M. (2019). Forecasting unknown-unknowns by boosting the risk radar within the risk intelligent organisation. *International Journal of Forecasting, 35*(2), 644–658.
Möller, N., & Wikman-Svahn, P. (2011). Black elephants and black swans of nuclear safety. *Ethics, Policy & Environment, 14*(3), 273–278.
Morrisons Annual Report and Financial Statements 2019/20. Available at:https://www.morrisons-corporate.com/investor-centre/annual-report/ (accessed on 26th September 2020).
Motarjemi, Y., & Lelieveld, H. (2014). Fundamentals in management of food safety in the industrial setting: Challenges and outlook of the 21st century. *Food safety management*. Academic Press.
Murphy, J. F., & Conner, J. (2014). Black swans, white swans, and 50 shades of grey: Remembering the lessons learned from catastrophic process safety incidents. *Process Safety Progress, 33*(2), 110–114.
Neumeyer, E., & Plümper, T. (2007). The gendered nature of natural disasters: The impact of catastrophic events on the gender gap in life expectancy, 1981–2002. *Annals of the Association of American Geographers, 97*(3), 551–566.
Orozco-Fuentes, S., Griffiths, G., Baggaley, A. W., Parker, N. G., Holmes, M. J., Ettelaie, R., et al. (2019). Early warning signals in plant disease outbreaks. *Ecological Modelling, 393*, 12–19.
Paté-Cornell, E. (2012). On "black swans" and "perfect storms": Risk analysis and management when statistics are not enough. *Risk Analysis: International Journal, 32*(11), 1823–1833.
Pavlov, A., Ivanov, D., Pavlov, D., & Slinko, A. (2019). Optimization of network redundancy and contingency planning in sustainable and resilient supply chain resource management under conditions of structural dynamics. *Annals of Operations Research*, 1–30.
Peters, D. P., Pielke, R. A., Bestelmeyer, B. T., Allen, C. D., Munson-McGee, S., & Havstad, K. M. (2004). Cross-scale interactions, nonlinearities, and forecasting catastrophic events. *Proceedings of the National Academy of Sciences, 101*(42), 15130–15135.
Rauschmayer, F., Bauler, T., & Schäpke, N. (2015). Towards a thick understanding of sustainability transitions—linking transition management, capabilities and social practices. *Ecological Economics, 109*, 211–221.
Rortais, A., Belyaeva, J., Gemo, M., Van der Goot, E., & Linge, J. P. (2010). MedISys: An early-warning system for the detection of (re-) emerging food-and feed-borne hazards. *Food Research International, 43*(5), 1553–1556.
Rosenfeld, J. S. (2002). Functional redundancy in ecology and conservation. *Oikos, 98*(1), 156–162.
Ross, H. (2008). United Kingdom: Recent developments in the UK. *European Food and Feed Law Review, 3*(1), 52–54.
Roy, H. E., Peyton, J., Aldridge, D. C., Bantock, T., Blackburn, T. M., Britton, R., et al. (2014). Horizon scanning for invasive alien species with the potential to threaten biodiversity in Great Britain. *Global Change Biology, 20*(12), 3859–3871.
Rumsfeld, D. (2002). *"Department of defense news briefing." US department of defense*. February 12th 2002 Available at: http://archive.defense.gov/Transcripts/Transcript.aspx?TranscriptID=2636. (Accessed 14 September 2019).
Schoenherr, T., Narasimhan, R., & Bandyopadhyay, P. (2015). The assurance of food safety in supply chains via relational networking: A social network perspective. *International Journal of Operations & Production Management, 35*(12), 1662–1687.
Shakerian, A., Khamesipour, F., Rahimi, E., Kiani, P., Shahraki, M. M., Pooyan, M., & Tyan, Y. C. (2018). Melamine levels in food products of animal origin in Iran. *Revue de Medecine Veterinaire, 169*, 7–9.
Sheffi, Y., & Rice, J. B., Jr. (2005). A supply chain view of the resilient enterprise. *MIT Sloan Management Review, 47*(1), 41.
Shekarian, M., Nooraie, S. V. R., & Parast, M. M. (2020). An examination of the impact of flexibility and agility on mitigating supply chain disruptions. *International Journal of Production Economics, 220*, Article 107438.
Simchi-Levi, D., Wang, H., & Wei, Y. (2018). Increasing supply chain robustness through process flexibility and inventory. *Production and Operations Management, 27*(8), 1476–1491.
Soon, J. M., Manning, L., & Smith, R. (2019). Advancing understanding of pinch-points and crime prevention in the food supply chain. *Crime Prevention and Community Safety, 21*(1), 42–60.
Sornette, D. (2002). Predictability of catastrophic events: Material rupture, earthquakes, turbulence, financial crashes, and human birth. *Proceedings of the National Academy of Sciences, 99*(suppl 1), 2522–2529.
Sornette, D. (2009). *Dragon-kings, black swans and the prediction of crises*. arXiv preprint arXiv:0907.4290.
Spink, J. (2013). *Beware the black swans of food fraud*. Available at: http://foodfraud.msu.edu/2013/05/15/beware-the-black-swans-of-food-fraud/. (Accessed 4 August 2019).
Sreedevi, R., & Saranga, H. (2017). Uncertainty and supply chain risk: The moderating role of supply chain flexibility in risk mitigation. *International Journal of Production Economics, 193*, 332–342.
Stewart, M., & Ivanov, D. (2019). Design redundancy in agile and resilient humanitarian supply chains. *Annals of Operations Research*, 1–27.
Suchý, P., Straková, E., Herzig, I., Staňa, J., Kalusová, R., & Pospíchalová, M. (2009). Toxicological risk of melamine and cyanuric acid in food and feed. *Interdisciplinary Toxicology, 2*(2), 55–59.
Taleb, N. N. (2007). *The black swan: The impact of the highly improbable*. London: Penguin.
Tesco. (2020). *Annual report and financial Statements 2020*. Available at: https://www.tescoplc.com/media/755761/tes006_ar2020_web_updated_200505.pdf. (Accessed 26 September 2020).
Todd, E. C. D. (2011). The international risk governance council framework and its application to Listeria monocytogenes in soft cheese made from unpasteurised milk. *Food Control, 22*(9), 1513–1524.
Tsakalidis, A., Gkoumas, K., van Balen, M., Haq, G., Ortega Hortelano, A., Grosso, M., et al. (2019). *TRIMIS as a support tool for transport research and innovation horizon scanning*. No. JRC113964).
Tummala, R., & Schoenherr, T. (2011). Assessing and managing risks using the supply chain risk management process (SCRMP). *Supply Chain Management: International Journal, 16*(6), 474–483.
Van der Fels-Klerx, H. J., Van Asselt, E. D., Raley, M., Poulsen, M., Korsgaard, H., Bredsdorff, L., et al. (2018). Critical review of methods for risk ranking of food-related hazards, based on risks for human health. *Critical Reviews in Food Science and Nutrition, 58*(2), 178–193.
Wardman, J. K., & Mythen, G. (2016). Risk communication: Against the gods or against all odds? Problems and prospects of accounting for black swans. *Journal of Risk Research, 19*(10), 1220–1230.
Weick, K. E. (1995). *Sensemaking in organizations*. Thousand Oaks: Sage Publications.
Will, R. G., Ironside, J. W., Zeidler, M., Estibeiro, K., Cousens, S. N., Smith, P. G., et al. (1996). A new variant of Creutzfeldt-Jakob disease in the UK. *The Lancet, 347*(9006), 921–925.
Wu, J. Y., & Hsiao, H. I. (2020). Food quality and safety risk diagnosis in the food cold chain through failure mode and effect analysis. *Food Control*, 107501.
Zhu, X., Huang, I. Y., & Manning, L. (2019). The role of media reporting in food safety governance in China: A dairy case study. *Food Control, 96*, 165–179.
Zhu, H., & Kannan, K. (2018). Continuing occurrence of melamine and its derivatives in infant formula and dairy products from the United States: Implications for environmental sources. *Environmental Science and Technology Letters, 5*(11), 641–648.
Zio, E. (2016). Challenges in the vulnerability and risk analysis of critical infrastructures. *Reliability Engineering & System Safety, 152*, 137–150.