Developing Frameworks to Understand Disaster Causation: From Forensic Disaster Investigation to Risk Root Cause Analysis

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Abstract

The Sendai Framework for Disaster Risk Reduction 2015-2030 calls for science to support policy move towards more holistic solutions to disaster risk. This paper outlines an original framework to promote inter-disciplinary research into disaster causation, identifying the basis for holistic solutions. The PEARL Risk Root Cause Analysis framework responds to limits identified in the established FORensic INvestigations of disasters (FORIN) approach to root cause analysis. The paper documents a systematic review of the FORIN approach as a starting point for the development of the PEARL framework. The proposed PEARL framework offers a broad and adaptable conceptual, methodological and practical approach. In particular, we demonstrate the centrality of governance, including the role of disaster risk management in risk creation, of bringing historical insights into contemporary and future scenarios planning and of integrating research methods. These core elements can assist in repositioning science to better support the goals of the Sendai Framework.

1. Introduction

The numbers of recorded disaster events, numbers of people affected and economic losses (both total and as a proportion of livelihoods) continue to grow (UNISDR 2015). This is despite a much improved science base. If we know more about hazard, vulnerability and resilience then why is risk and loss growing? Understanding how efforts to control risk and hazard are being out-weighed by the processes generating new risks calls for changes in our modes of research and practice (Oliver-Smith et al. 2016). This is buttressed by the text of Sendai Framework for Disaster Risk Reduction 2015-2030, which calls for science to support policy move towards more holistic solutions to disaster risk (Pelling et al. 2016). As well as inter-disciplinary research that addresses the underlying drivers of risk and disaster, the Sendai Framework advocates a more systematically organized evidence base for disaster risk reduction policy (ibid.). The process of achieving both aspects will benefit from structures to frame – but not direct – knowledge production, such as that offered by root cause analysis.

Root cause analysis has been described as "a structured investigation that aims to identify the true cause of a problem and the actions necessary to eliminate it" (in DKKV 2012, p.12). There is still limited knowledge about the root causes of disaster risk. Existing disaster assessment and evaluation methodologies provide important overviews of current vulnerabilities, capacities and post-disaster conditions, but tend to stop short of investigating why risks and vulnerabilities arise (DKKV 2012). The FORensic INvestigations of disasters (FORIN) approach provides one model for root cause analysis.

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Developed by the Integrated Research on Disaster Risk (IRDR) program of International Council for Science (ICSU), International Social Science Council (ISSC) and United Nations International Strategy for Disaster Reduction (UNISDR), FORIN aims to deepen the spatial and temporal scales of disaster analysis and integrate a systematic understanding of the links between disasters and development (IRDR 2011; Oliver-Smith et al. 2016). It offers a broad set of methodologies that have in common the aim of unpacking key events to better surface underlying root causes (ibid.). This aims to move beyond the impasse of knowledge without action by making visible to policy actors, practitioners, those at risk and researchers the contribution of key decision-making processes to the accumulation of risk, its social and spatial distribution and its expression in disaster events.

In this paper, we review the FORIN approach and build a focused contribution to FORIN studies through the development of an original Risk Root Cause Analysis framework. The motivation for the review and extension of the FORIN approach presented in this paper has come within a European Commission Seventh Framework Programme project: Preparing for Extreme And Rare events in coastaL regions (PEARL). The overall goal of PEARL is "to develop adaptive, sociotechnical risk management measures and strategies for coastal communities against extreme hydro-meteorological events minimising social, economic and environmental impacts and increasing the resilience of Coastal Regions in Europe." See http://www.pearl-fp7.eu/ for further details. To this end, PEARL adopts a holistic, systems-oriented approach that aims to connect technology with the social and natural processes that give rise to risk (Vojinovic 2015). Root cause analysis provides a critical pathway through which these processes can be investigated, and the findings incorporated in a broader suite of methodologies for risk assessment, such as quantitative vulnerability assessments or agent-based modelling work. In this way, PEARL opened up space to review and reflect on the FORIN approach, and its place among other existing root cause analysis frameworks. The specific demands of PEARL, in terms of the scales of analysis and need to connect contemporary expressions of the root causes of risk with their historical coevolution rather than explaining the past causes of a recent event and learning lessons from this, contributed to the building of a distinct PEARL Risk Root Cause Analysis framework using insights from the systematic review of FORIN.

The paper first sets out the main elements of FORIN and the review, which comprised of a systematic assessment of FORIN-aligned and non-aligned case studies and systematic comparison of FORIN with other aligned root cause frameworks. The paper then outlines five central elements for the development of the FORIN framework in this case. In Section 3 the paper draws from this review to propose an original PEARL Risk Root Cause Analysis framework. Section 4, in conclusion, overviews the new research and policy space that this framework opens.

2. The FORIN Approach to Understanding Risk Root Causes: Overview and Review

The FORIN approach stands out as an international benchmark for risk root cause analysis. FORIN has progressed through two key models, FORIN I (IRDR 2011) and FORIN II (Oliver-Smith et al. 2016). FORIN I defines the core elements and aims of the FORIN approach, FORIN II refines methods and vision. Both FORIN I and FORIN II reflect UNISDR priorities for integrated policy development and interpret this as a call for increased work on risk governance. The two FORIN models help to provide structured science engagement with the respective aims of the Hyogo Framework for Disaster Risk Reduction 2005-15 and Sendai Framework 2015-30. As well as bringing governance to the heart of analysis, other key characteristics of the FORIN framework include i) risk assessment, made up of causal agents, social systems and infrastructure ii) understanding and awareness of underlying causal processes and iii) outcomes and impacts in terms of sectors, spatial distribution and susceptible populations and in terms of risk reduction and enhancing resilience and iv) the application of the framework across the phases of antecedent conditions, emergency response and long-term recovery. For each element, FORIN proposes a set of key questions to guide investigations.

FORIN I (IRDR 2011) provides two sets of categories for organizing FORIN studies, event type and methodological pathway. With regards to the first category, event type, studies may concern specific events (e.g., the Hanshin earthquake, Japan); recurrent events (e.g., flooding in Mozambique); thematically important dimensions (e.g., school and hospital safety, trans-boundary risks) or risk drivers (e.g., management, poverty, governance). Four types of methodological pathway are then proposed: Critical cause analysis, that seeks to identify the root causes of disaster events; Meta-analysis, that systematically reviews the available literature to identify and assess common findings across diverse studies as regards causal linkages as well as the effectiveness of interventions; Longitudinal analysis, or repeated observations of comparable events, either geographically comparable or comparable in situ; and Scenarios of disaster, or science-based retrospective re-constructions of specific conditions, causes and responses involved in particular destructive events selected on the basis of a known hazard that represents a realistic and possibly inevitable future event.

2.1 Critical review of FORIN Case studies

In 2014, researchers at King's College London undertook a three-step desk review to explore the conceptual and practical value of FORIN. This included reviews of empirical work that had formally adopted the rubric of FORIN, studies that had applied methods incorporated by the FORIN approach but had not formally self-identified with FORIN and a review of the DKKV methodology, a cognate approach. The results of these reviews are presented here, offering a first systematic review of the FORIN approach in addition to helping chart the development of the PEARL Risk Root Cause Analysis framework presented in Section 3.

In reviewing those studies identifying with FORIN, a first step was to benchmark these against the components of the FORIN conceptual framework, its event types and methodological pathways. The aim was to assess the comprehensiveness of deployment. We reviewed only for the deployment of methodological tools, not for the quality of the methodology or data produced, nor of the impact of any study on practice.

An example of the matrix used for each case study to do this is shown below (Fig. 1). No single study covered the full range of FORIN questions, although the studies of the Great East Japan Earthquake and Tsunami (Fujiwara 2011, Sagara 2011 and ICHARM 2011) use all FORIN methods as well as cover all the framework elements specified by FORIN. As the 2016 FORIN II version notes, a fully comprehensive FORIN is an intensive effort which cannot be mounted and accomplished quickly, and may require significant resources to be achieved.

Figure 1: Visual assessment of FORIN framework areas covered by Huang et al. (2013)

DISASTER: (Typhoon Morakot, 2009)		FORIN Framework element																																						
Taiwan, Tailin Huang		Governance/Priority						Risk Assessment					Understanding/awareness						Outcomes/impacts									Risk reduction						Enhancing resilience						
Methodological pathway	Disaster typoology	8	11	11a	18	19	G10	1	2	2a	6	7	3	4	5	6	7	20	12	13	14	15	16	17	G2	G6	G9	9	10	G1	G4	G5	G8	15	15a	15b	15c	15d	G3	G7
Critical cause analysis	Specific events																																							
	Recurrent events																																							
	Thematically important dimensions																																							
	Risk drivers																																							
Meta-analysis	Specific events							x	x	x		x	x	x			x						x		x	x	x					x	x			x				
	Recurrent events																																							
	Thematically important dimensions																																							
	Risk drivers																																							
Longitudinal analysis	Specific events																																							
	Recurrent events																																							
	Thematically important dimensions																																							
	Risk drivers																																							
Scenarios of disaster	Specific events																																							
	Recurrent events																																							
	Thematically important dimensions																																							
	Risk drivers																																							

Figure 1 shows the matrix that was used to assess the deployment of the FORIN framework across studies explicitly identifying with the FORIN approach, filled out here for just one of the case studies, that of Typhoon Morakot, Taiwan (in the study by Huang et al., 2013). The matrix charts the methodological pathway and event type discussed by each case study down the vertical axis, and the range of FORIN questions discussed by each case study across the horizontal axis (with the specific FORIN questions ordered under each element of the Framework). Darker shading was used to indicate a stronger engagement with the relevant FORIN question, and lighter shading weaker engagement with the relevant question. The idea of the matrix was to provide an accessible overview of the ways in which the FORIN Framework had been taken up and developed in application.

The case studies were also analyzed for what they tell us about the strengths and limits of, and gaps in FORIN. FORIN provides a broad and adaptable framework for the investigation of disaster root causes across scales and types of disaster. The comprehensive and inter-disciplinary nature of the framework reveals how disasters unfold as the result of development and social processes, supporting conceptual work on disasters that seeks to re-frame them as such (Collins 2009).

Table 1 provides a summary of the review of those studies explicitly deploying a FORIN approach. FORIN enabled work that aimed to integrate different scales of analysis and is revealing of the interactions between socio-economic and political and risk dynamics (Huang et al. 2013; Naruchaikusol, Beckman, and Mochizuki 2013; Castillo 2013). The objectives, methods and questions inspired by FORIN were broad enough to allow for its adaptation to different contexts and forms of risk while the range of methodological pathways allowed for scenario analysis alongside historical methods. FORIN's methodological approach also fostered the inclusion of multiple stakeholders in the research process (Faustino-Eslava 2013), and the innovation of the FORIN narrative (or initial, top-line FORIN study) allowed for rapid studies that could be expanded over time (Castillo 2013).

Limits included the difficulties in defining the scope of FORIN especially the analysis of long-term changes in average climate variables alongside disaster events. Common gaps included methods and concepts for analyzing causal relationships as well as questions about infrastructural damages and risk propagation. More positively, one study (Castillo 2013) had gone beyond FORIN's stated aims to include a stronger emphasis on transformative change as a standpoint for understanding risk reduction processes (going beyond 'Resilience Enhancement' as the original element of the FORIN framework to encompass the need for structural change in risk reduction), and used the dimensions of hazard, vulnerability and exposure to better analyze risk accumulation processes

(Castillo 2013). Both of these latter elements were incorporated into the Risk Root Cause Analysis framework, and discussed further in FORIN II. Castillo (2013) also incorporated the research cycle itself into the FORIN framework, modifying the capacity of relevant stakeholders, in the spirit of the research-policy integration proposed by FORIN.

Table 1: Summary of the strengths, limits and gaps in FORIN

Study	Strengths of FORIN	Limits of FORIN	Gaps in FORIN
Naruchaikusol, Beckman & Mocjizuki 2013	Allows for the investigation of the links between disaster risk and development processes at different scales and the effects of cumulative decision-making at these scales The scenario method allows for integration of predictive methods		
Huang et al. 2013	Its conceptual view of disaster as inseparable from everyday and wider development and societal processes; and disasters as the result of the outcome of interaction between different systems and different phenomena Its inter-disciplinary framework, and the importance of a historical approach for policy learning, the results of this assist comprehensive scenario planning	Defining where the limits of 'disaster' as a social disturbance end, and therefore how to define relevant stakeholders; lack of discussion of the implications for policy	The authors turn to systems theory for a conceptual and methodological basis for the analysis of causal pathways; they use this to establish the most critical phenomena and main 'storylines' that explain the relationships between causal factors
Castillo 2013	Its comprehensive, inter-disciplinary approach integrates perspectives of different stakeholders Adaptability of FORIN to the context of climate change (Also innovation of the FORIN narrative allowed for preliminary studies to be produced)	Influence of long-run changes in average climate variables The practical challenges of inter-sectoral work	Models were used to enhance the predictive capacities of the FORIN approach, allowing for analysis of the common variables affecting risk and resilience to disasters and climate change The objectives were modified to include an element related to transformational change

			The original FORIN framework was also modified to include a more explicit characterization of risk (as the holistic analysis of hazard, exposure and vulnerability in the past, the present and projected into the future), the research cycle itself and capacity building as a core element by which the research results are implemented. The report included modifications or the context of climate change.
Faustino-Eslava et al. 2013	The use of FORIN as a predictive tool even where there is no history of disaster The inclusion of multiple stakeholders in discussions of risk mitigation measures		
Fujiwara, Sagara & ICHARM studies of GEJET, 2011			FORIN lacks detailed questions to guide common analysis of damage to infrastructure networks, and damage propagation between networks

2.2 Critical analysis of FORIN analytic elements

A second step of this analysis was to review 40 studies that had deployed methodological tools supported by FORIN, but that did not self-identify as FORIN studies. This broadened the pool of knowledge available to the analysis and subsequent framework development. The review categorized the findings of these studies according to the core elements of the FORIN framework, its event types and methodological pathways. This allowed elements of key methodological and research cross themes that could actively contribute to the PEARL research framework to be identified as well as providing an active gap analysis frame from which to innovate. The exercise confirmed the adaptability of FORIN, while the specific insights from particular studies for the resulting analysis are discussed in the section below. Table 2 also demonstrates the importance of deploying independent studies that can be grouped under a common methodological and conceptual framework, and so the value added that FORIN – and related frameworks - can bring to the science and policy communities.

Table 2: Summary of analysis of studies of disaster causation according to FORIN framework element, grouped by phase of the disasters cycle

See Table 2 in Separate File

2.3 FORIN and other Root Cause Analysis Frameworks

As a final step in building the PEARL Risk Root Cause Analysis framework we also augmented the review of FORIN through a review of a parallel methodology developed by UNU-EHS on behalf of Deutsches Komitee für Katastrophenvorsorge / German Committee for Disaster Reduction (DKKV) (DKKV 2012). We found the DKKV methodology to be compatible with FORIN's aims and components and that many of its most important contributions were incorporated in the revision of FORIN II. Specifically the DKKV approach stressed that disaster risk root cause analysis entails identifying causes in a multi-dimensional and comprehensive manner. It separated drivers from root causes, where drivers were the activities and processes that translate root causes into unsafe conditions, while root causes were the structures and processes that go beyond an individual crisis or event. The Disaster Risk Management process itself was incorporated as an element driving vulnerability (discussed further below). It also differentiated generic from place/hazard specific root causes. It grouped causal pathways according to field (Development, Awareness and Perception, Governance, Political Environment and Physical and Environmental conditions) and unpacked the elements of vulnerability and their particular drivers. These findings help to verify the conceptual strength of FORIN.

Beyond verifying these elements, the DKKV review identified a new dimension to risk root cause analysis to be taken forward in PEARL framework development. Where FORIN emphasized a largely pre-disaster perspective, the DKKV framework incorporated a near-time vulnerability assessment undertaken in the post-disaster phase. This potentially widens the analytical scope of FORIN and enhances policy relevance by taking a disaster event as a starting point from which to look forwards (to determine future risk) as well as backwards (in diagnosing the accumulation of past risk and loss) in time.

2.4 Critical analysis of FORIN analytic elements

On the basis of the systematic review process discussed above, five core elements were identified for the future development of root cause analysis frameworks. These form the basis of the PEARL Risk Root Cause Analysis framework proposed in Section 3 and include the following:

1. Structuring understanding of the governance context for disaster management
2. The role of the disasters cycle in perpetuating risk
3. Integrating backward-looking and forward-looking analysis
4. Developing methods for analyzing causal pathways
5. Developing indicators for comparative analysis over time and through which to assess the impact of FORIN and other root cause studies

This section develops these points before the following section discusses their integration into an original framework for understanding the risk root causes of extreme events.

2.4.1 Structuring understanding of the governance context for disaster management

The governance component of FORIN is arguably the linchpin of this approach. However, different understandings of governance could be utilized to unpack more clearly questions of decision-making and capability? Of the 40 studies of disaster causation reviewed for this paper, particular studies emphasized elements not yet included in FORIN: the role of performance and interpretation in organizational responses to disaster (Adrot 2013), the role of institutional culture and beliefs (Constantinides 2013) and the lack of communication and understanding between institutions (Emdad Haque 2000). The existing FORIN approach would seem to emphasize an actor-oriented, top down orientation. Other FORIN-inspired studies, such as the STREVA project to examine the root causes of volcanic risk, for example, explore what defines institutional capacity at different scales and how it is influenced by the relationship between formal and informal institutions, networks between different actors and coherence across those scales (Wilkinson 2013). As well as this vertical, multi-scalar conception of tiers of governance, an institutional political economy approach can help unpack the horizontal relationships between different organizations within a particular institutional configuration.

The questions that arise, then, are how institutional capabilities to assess and manage risk (and the developmental drivers of risk) are shaped across these dimensions in the context of different political regimes (Pelling 2003), with different value orientations and social and cultural foundations, at different points in time (in particular when disasters open up ‘windows’ of opportunity for change)(Birkmann et al. 2010). Further questions might also address the role of disaster narratives in the process of disaster causation and the influence, for example, of the discursive production of disasters as amenable to technical solutions alone, or the labelling of affected communities as ‘responsible’ in ways that might be contested (Aragon-Durand 2007). This final sense of how notions of responsibility come to be used within the disaster-related discourses of different actors connects most strongly with a view of governance as a set of everyday practices which also influence how risk and vulnerability are experienced (Zeiderman 2012).

2.4.2 The role of the disasters cycle in perpetuating risk

The disasters cycle itself – preparedness, mitigation, response, recovery and reconstruction – is a process embedded in the institutions of governance that influences the occurrence of risk. The post-disaster phase is not simply the end point of the disaster event, but a process in its own right that has its own antecedents in the social, economic and institutional context and forms part of how we understand disasters as complex and unfolding phenomena, rather than single points in time (DKKV 2012). These antecedents merit their own forensic analysis: how and why were particular response options chosen, by what actors and with what results? This is often a neglected area of analysis with few studies tracking the influence of particular decision points on the generation of impact, though recent studies indicate the reconstruction process can have a considerable impact on human wellbeing and vulnerability (Medd et al. 2015). Problems with accessing insurance payments and secondary economic costs, as well as gains in reconstruction may be more important in some instances than the initial disaster. In addition, disasters might also be intensified and risks continue due to inappropriate disaster response strategies (DKKV 2012). The nature of response and recovery determines how existing vulnerabilities are ameliorated or exacerbated and may preclude as well as enable policy and planning changes for enhanced resilience (IPCC 2012).

2.4.3 Integrating backward-looking and forward-looking analysis

The case studies adopting the formal rubric of FORIN have already demonstrated how scenario-based analysis can be integrated with historical root cause analysis, with two of the FORIN case studies using down-scaled climate change models alongside other FORIN methods. In addition, one FORIN case study focuses on providing a baseline analysis of risk in an area under threat, but with no history of disaster (Faustino-Eslava 2013). The predictive capacity and conceptual focus of FORIN in this regard merits further investigation. A FORIN-like approach could be used in conjunction with other predictive analyses, like the social vulnerability index (Cutter et al. 2003) or the disaster risk index (Peduzzi et al. 2009), to identify vulnerability hotspots and enhance pre-disaster actions. Conceptually, the FORIN emphasis on historical root cause analysis could be developed with an approach that moves to understand how historic drivers connect with contemporary manifestations (as premised by the DKKV approach), and might drive risk into the future.

2.4.4 Developing methods for analyzing causal pathways

How do we understand how actions and decision-making are set within the interaction of social and ecological processes in ways that are dynamic, and potentially non-linear (Miller et al. 2010)? In addition to making further distinctions between types of causal process, as discussed above, possible methods for analyzing causal processes merit further discussion. As just one example, two of the FORIN case studies used systems analysis as a methodological and conceptual guide for analyzing causal processes, through the construction of causal loops and analysis of the strength of different causal phenomena.

2.4.5 Developing FORIN indicators for comparative analysis over time and through which to assess the impact of FORIN

While the FORIN framework incorporates a number of thematic areas which map onto specific research questions, developing indicators on the basis of these would facilitate analysis of risk over time and across different cases. The development of consistent and useful sets of indicators of both social and natural dimensions of disaster risk poses two distinctly inherent problems with respect to a complexity of the research parameters: (1) keeping the number of indicators manageable and (2) resolving differences in perspectives and terminology between social and natural system scientists (Loomis et al. 2014). These issues would have to be overcome before a comprehensive methodology could be developed. However, such a methodology could also facilitate both the measurement of the impact of FORIN (assuming that FORIN's impact can be attributed from changes in risk processes). It might also assist in translating the findings of FORIN studies into tractable frameworks that can be utilized by decision-makers to improve disaster management processes (akin to the 'check list' used in the DKKV methodology).

3 The PEARL Risk Root Cause Analysis framework

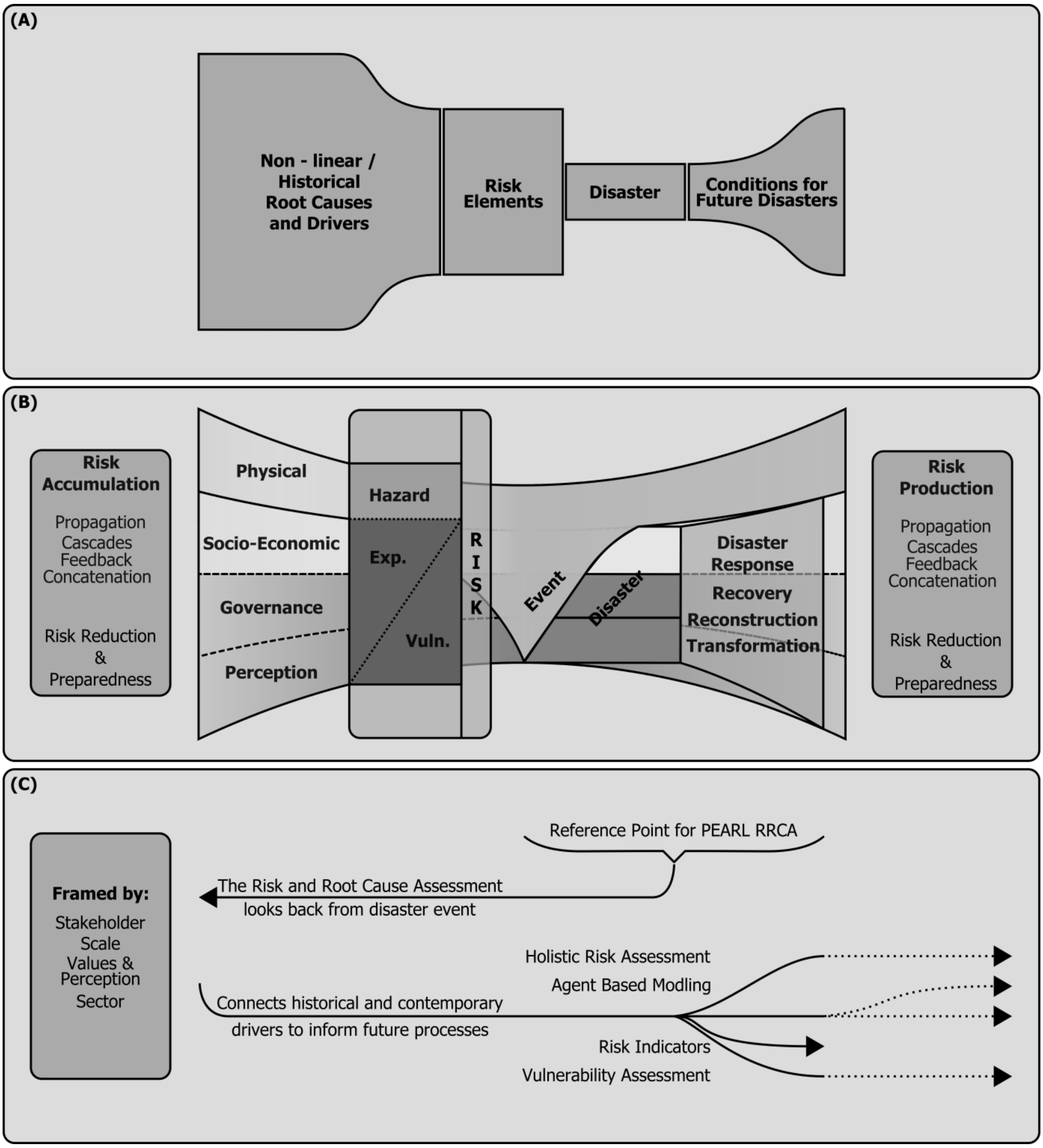
The PEARL project has brought additional requirements to the approaches reviewed in this paper. These combined with the findings of the review process generate the shape of the PEARL Risk Root Cause Analysis framework presented in this section.

A key consideration was differing requirements of scale. While FORIN studies have so far concentrated on single, large disaster events, PEARL has an interest in including small-scale, possibly recurrent, but locally high-impact, disasters. In accepting this broadening of application additional questions are opened that the framework needs to consider. Most important are how risks cascade (between first order, second order and third order, or direct and indirect, impacts) and propagate (across scales and temporal perspectives). Further, by incorporating local risk and loss, PEARL introduces a more diverse scale of institutional analysis. Local government and associated local scale actors become the primary stakeholders for development and risk management decision-making in smaller/recurrent events, mediating between local loss/risk and national and international actors. Mediation becomes a key element of the PEARL framework and allows a tracking of regional/national root causes through local institutions. This is a long-standing gap in studies of disaster risk (Wisner et al, 2004).

In emphasizing the need for science to engage with policy and practice, the PEARL Risk Root Cause Analysis framework also seeks to connect contemporary expressions of the root causes of risk (building on DKKV 2012) with their historical coevolution as explained through the FORIN method. This is a shift from the original FORIN method which was primarily interested in explaining the past causes of a recent event and learning lessons from this to one which takes the disaster as a focusing event from which to look backwards and forwards in time. Retaining the disaster as the starting point maximizes opportunity for narrative accounts to draw out attribution and illustrate the intervention of other drivers as time accumulates before and after an event.

The following figure sets out the proposed PEARL Risk Root Cause Analysis framework. It is divided into three parts: (A) Overall concept, (B) Process, (C) Methodological Approach. Central to the framework is the inseparability of risk from the underlying root causes (A). These are considered as manifestations of physical, governance, socio-economic and perception processes (B), that are disturbed by a physical event, affecting the remaining three spheres and causing a disaster. The process of responding to a disaster – the trajectories of response, recovery, reconstruction and transformation – both has its own antecedents in the historical context, as well as shaping the new context for risk production going forward. PEARL will assess the process of accumulating and producing risk before, during and after an event, look at the underlying drivers and root causes and – building on this historical perspective – inform future (planning) processes (C).

Fig. 2 The PEARL Risk Root Cause Analysis (RRCA) Framework



Source: Fraser et al. 2014.

(A) Concept

The overall concept of the framework is that the historical **root causes** of **risk** are translated by the **drivers of hazard, vulnerability** and **exposure** into a situation of endangerment (risk). Risk at any given time is an evolving process that can be traced back to its root causes. The occurrence of a disaster and the disaster response sets the conditions for the future, and the magnitude and form of any future disasters.

(B) Process

The framework is centered on dynamic **physical, socio-economic, governance** and **perception** processes. These four are interlinked in a non-linear fashion and in continuous exchange. Therefore the **risk** – as a function of **hazard, exposure** and **vulnerability** – is displayed at a single point but could be assessed at any given time step (depending on the availability of data). Investigating and learning from the interaction of root causes that lead to an expression of risk (or loss) at any one moment is the analytical focus of the PEARL Risk Root Cause Analysis framework. A disaster is signified in the model by the intersection of hazard with social processes. The hazard event impacts on these spheres causing losses and damages.

Following the disaster, **Disaster Response, Recovery, Reconstruction** and **Transformation** processes both influence the physical, socio-economic, governance and perception factors within a spatial entity and are influenced by the historical physical, socio-economic, governance and perception context. These aspects contribute – either positively or negatively – to the accumulation and production of risk. The disasters 'cycle' refers to the stages of pre- and post- disaster response, with appropriate actions at all stages necessary to mitigate disaster losses and damages. This cycle of **Risk Reduction and Preparedness** encompasses response, recovery, reconstruction and transformation as well as mitigation and preparedness measures taken in anticipation of a disaster event, but not necessarily following a disaster. Risk reduction and preparedness is therefore represented in both the Risk Accumulation and Risk Production boxes as a process that unfolds before and after an event. While the terms Risk reduction and preparedness are often used to refer to the application of a narrow set of pre-disaster management tools, here they are used in the fullest and most meaningful sense to describe the purpose of all disaster management tools, or the highest order goal of the disasters cycle.

In taking disaster response, recovery and reconstruction measures valuable opportunities arise to reduce and prepare for risk in ways that not only build back to 'normal', or the state of affairs prior to the disaster event, but 'build back better', preventing the disaster from re-occurring, or at least to the same magnitude. This is captured by the inclusion of the term Transformation, to refer to the process of re-aligning the structures underpinning the disaster to ensure a resilient and sustainable future in a given context. The notion of resilience – the goal, or robustness of a particular system to cope with and recover from disaster events – is therefore subsumed by the term transformation. Sustainable refers not only to environmental sustainability but also social justice and equity, for both current and future generations.

The terms to the left and right of the figure indicate the dynamics of the way in which risks occur. **Risk propagation** refers to the influence of risk over wide spatial and temporal domains, or how risk may have systemic impacts which may not be easily identifiable and may manifest themselves at different points in time to the actual disaster event. **Risk cascading** refers to the cascade of effects of risk from first order, direct impacts to second order, indirect impacts and to third order, systemic risks. **Feedback** refers to the ways in which both the disaster and post-disaster processes (including disaster risk management itself) have impacts that may feed back into the underlying conditions for ongoing risk and subsequent disasters, potentially altering the nature of these conditions. **Concatenation** refers to situations where one extreme event precipitates one or more other extreme events. **Risk accumulation** refers to the potential result of these processes, where risks concentrate across different spatial and temporal scales.

It is important to underline the possible non-linear nature of the processes underlying risk. In a risk cascade, for example, there is no necessary linear relationship between first order and second order impacts. The physical, socio-economic, governance and perception drivers of risk may inter-connect to create risk in non-linear ways. In addition, there is uncertainty at any given moment in time about future risks and disaster events either due to information deficits or disagreements about what is known or knowable. Such uncertainties shape how risks are estimated and affect decision-making and actions in the governance and socio-economic domains.

(C) Methodological Approach

The reference point for the framework is the study of disaster impacts and losses and post-disaster development trajectories. This focal point in time is bracketed in Figure 2C. It provides a critical 'window' through which the historical drivers of risk can be assessed, and their manifestations in the contemporary context analyzed. This perspective is then used to inform future risk scenarios. The interpretation of the event, disaster and post-disaster processes is framed by the perspectives and values of the stakeholders interviewed, the sectors analyzed and the scale of the analysis. The Risk and Root Cause Assessment itself, with its focus on bringing a historical perspective into the present, feeds into other methodologies in PEARL which will be used to benchmark and project future risks. These are a) a vulnerability assessment b) an agent-based model and c) risk and root cause indicators which can be used to assess efforts to address disaster root causes over time.

The application of the PEARL Risk Root Cause Analysis framework centred on case study analysis in urban coastal contexts of Europe and the Caribbean (see Fraser, 2016; Mavrogenis, 2016 and Scolobig, 2016). The case study research used qualitative investigation to draw out narrative attributions of root causes and drivers for key focal disaster events, and explore the manifestation of these root causes and drivers into the present and possible future, across as wide a range of stakeholders as possible. This included stakeholders involved in different phases of the disasters cycle, from land use planning pre-disaster to emergency response post-disaster, and across different spatial and jurisdictional levels of governance (including regional and national government actors as well as local government representatives, for example). The framework developed for the stakeholder interviews broke down the ways in which different elements of risk (hazard, exposure and vulnerability) were driven by the inter-acting causal pathways identified in the PEARL Risk Root Cause Analysis framework (physical, socio-economic, governance and perceptions and beliefs) across the different temporal dimensions of interest (historic, contemporary, future). The resulting qualitative analysis – presented in a series of Risk Root Cause Analysis reports – informed the design and use of other methodologies in PEARL aiming to quantify vulnerability (as the outcomes of risk accumulation processes) and model agent behavior within the system boundaries also revealed through the qualitative Risk Root Cause Analysis approach. The comparative case study approach, which examines similar sets of events across multiple case studies, in turn provides the evidence base for the development of root cause indices for small-scale but high-impact coastal flooding risk and disasters.

4 Conclusion

The findings of the systematic review presented in this paper verify that FORIN provides a broad and adaptable approach for the study of disaster root causes. FORIN's objectives and framework resonate well across a wide range of studies of disaster causation. Studies that used the FORIN framework were successfully guided by its principles of holism and multi-disciplinarity with the inclusion of a wide range of stakeholders in the analysis process. Undertaking a 'full' FORIN, however, was shown to require time and resources that were beyond the scope of most existing studies, although the FORIN narrative approach has been used successfully as a starting point for inter-sectoral analysis.

The systematic review also highlights areas for the further development of FORIN. This includes a more structured approach to the investigation of governance elements that drive disaster reduction. It is these elements that have been taken forward to shape the proposed PEARL Risk Root Cause Analysis framework:

- institutional dynamics across scales,
- the incorporation of the disaster management cycle as a driver of risk and disaster,
- further discussion of the ways in which 'predictive' FORINs could employ tools from the social sciences such as vulnerability indices,
- the possible development of a set of comparison indicators for FORIN studies and the development of methods for causal analysis (and possible causal loops and feedbacks).

The proposed PEARL Risk Root Cause Analysis framework retains the central elements of FORIN and its emphasis on the inseparability of social and physical causal processes that need to be understood to tackle disaster risk. The framework then builds on the explicit inclusion of disaster governance as a causal pathway to risk mitigation or creation, the analysis of historical pathways to risk into the present and future and in the methodologies proposed to capture these more theoretical elements.

These findings have broader application. They point to areas where methodology is either underdeveloped or where studies have yet to provide the joined up evidence base for disaster risk reduction policy called for in the Hyogo and Sendai Frameworks. There are significant opportunities in the development of these areas for science to support policy and for policy and practice to become better acquainted with the needs of evidence based research.

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