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Science–policy–practice insights for compound and multi-hazard risks

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Abstract

When multiple weather-driven hazards such as heatwaves, droughts, storms or floods occur simultaneously or consecutively, their impacts on society and the environment can compound. Despite recent advances in compound event research, risk assessments by practitioners and policymakers remain predominantly single-hazard focused. This is largely due to traditional siloed approaches that assess and manage natural hazards. Hence, there is a need to adopt a more 'multi-hazard approach' to managing compound events in practice. This paper summarizes discussions from a 2-day workshop, held in Glasgow in January 2023, which brought together scientists, practitioners and policymakers to: (1) exchange a shared understanding of the concepts of compound and multi-hazard events; (2) learn from examples of science–policy–practice integration from both the single hazard and multi-hazard domains; and (3) explore how success stories could be used to improve the management of compound events and multi-hazard risks. Key themes discussed during the workshop included developing a common language, promoting knowledge co-production, fostering science–policy–practice integration, addressing complexity, utilising case studies for improved communication and centralising information for informed research, tools and frameworks. By bringing together experts from science, policy and practice, this workshop has highlighted ways

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to quantify compound and multi-hazard risks and synergistically incorporate them into policy and practice to enhance risk management.

KEYWORDS

compound events, multi-hazards, multi-hazard risks, risk management, science–policy–practice

1 | INTRODUCTION

When multiple weather-driven hazards such as heatwaves, droughts, storms or floods occur simultaneously or consecutively in time and/or space, their impact can be amplified relative to single hazard events. For instance, coastal flooding from tropical cyclones occurs generally through a combination of inland precipitation and storm surges (Eilander et al., 2023), and can exacerbate critical infrastructure damage, as shown by the flood impacts of Hurricane Sandy in New York City (Goulart et al., 2024). These multiple weather-driven events can be classified as 'compound events', which relate to the wider category of multi-hazard risks (see Table 1 for definitions).

Compound and multi-hazard risks have gained global recognition in recent decades (Ward et al., 2022). For example, the Intergovernmental Panel on Climate Change (IPCC) first adopted the term 'compound event' in the 2012 Special Report on Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation (SREX), and projects that such events will become more frequent under warming scenarios exceeding 2°C (IPCC, 2012), particularly impacting critical sectors such as agriculture. Similarly, the United Nations Office for Disaster Risk Reduction (UNDRR) Sendai Framework for Disaster Risk Reduction (2015–2030) highlights the need to prepare for and mitigate multi-hazard risks, including developing multi-hazard early warning systems globally (UNDRR, 2015). Recognising the urgency, the IPCC, UNDRR and the World Meteorological Organisation (WMO) have emphasized the need to prioritize compound and multi-hazard risk management and integrate it into disaster risk strategies (IPCC, 2021; UNDRR & WMO, 2022; van den Hurk et al., 2023).

The DAMOCLES European COST Action provided an interdisciplinary research network that connected researchers and practitioners to improve our understanding and modelling of compound events, thereby supporting the growth of the compound events research community during the period 2018–2023. DAMOCLES also promoted a bottom-up, impact-centric approach to compound events research. A bottom-up approach moves away from science-driven selection of research topics that could cause significant impacts towards a more pragmatic approach that grounds the focus of research on known extreme weather events—including compound events—that cause impacts (Bevacqua et al., 2021).

Central to this approach is collaboration with end-users. Working Group 2 of DAMOCLES was specifically established to connect scientists with a wider network of practitioners and policymakers for whom compound events are important in decision-making. These include policymakers, decision makers and practitioners from a wide range of sectors, including energy, infrastructure,

TABLE 1 Compound event and multi-hazard terminology.

Term	Definition
Compound event	'Compound weather and climate events refer to the combination of multiple drivers and/or hazards that contribute to societal or environmental risk' (Zscheischler et al., 2018).
Multi-hazard	'The selection of multiple major hazards that the country faces, and the specific contexts where hazardous events may occur simultaneously, cascading or cumulatively over time, and considering the potential interrelated effects' (UNDRR, 2017)
Multi-hazard risk	'Risk generated from multiple hazards and the interrelationships between these hazards (but not considering interrelationships on the vulnerability level)' (Zschau, 2017).
Multivariate compound event	'Where multiple drivers and/or hazards lead to an impact' (Zscheischler et al., 2020).
Pre-conditioned compound event	'Where weather and/or climate-driven preconditions aggravate impacts on a hazard' (Zscheischler et al., 2020).
Spatially compounding event	'Where hazards across multiple connected locations cause aggregated impacts' (Zscheischler et al., 2020).
Temporally compounding event	'Where successive hazards lead to an impact' (Zscheischler et al., 2020).

food and agriculture, ecosystem management, tourism, finance, health and disaster risk reduction. However, to date, research on compound events and multi-hazard risks has generally focused on the physical understanding of processes rather than improving preparedness and management in practice (van den Hurk et al., 2023). Furthermore, the understanding of compound events and multi-hazards, including identifying potential hotspots associated with the interaction of such processes and the global interconnections of the associated impacts, is still under-developed (Beevers et al., 2022).

In addition to the research gaps outlined, many policymakers and practitioners typically still approach risk assessments of extreme weather-driven events without considering compounding processes (e.g., Schlumberger et al., 2022; Scolobig et al., 2017; van den Hurk et al., 2023; Ward et al., 2022; Zscheischler et al., 2018). These single hazard risk assessments can lead to the potential under- or overestimation of risk (Schlumberger et al., 2022; van den Hurk et al., 2023; Ward et al., 2020; Zscheischler et al., 2018). Known challenges for incorporating compound event and multi-hazard thinking into practice include: the diverse language associated with complex hazards and risks (Ward et al., 2022); lack of clear guidelines for complex hazard and risk assessment and management (De Angeli et al., 2022; Ward et al., 2022); a focus on previous complex hazard and risk events without considering future scenarios (Gallina et al., 2016); and a lack of in-depth case studies on multi-hazard risk assessment and management (Ward et al., 2022).

To explore these challenges and future pathways, DAMOCLES organized a 2-day workshop, bringing together researchers, practitioners and policy makers to: (1) develop a shared understanding of compound and multi-hazard events and foster a common language; (2) document successful science–policy–practice interactions, drawing lessons from single and multi-hazard contexts for future application; and (3) propose recommendations for improving compound event and multi-hazard risk management. These research objectives shaped workshop discussions and the subsequent qualitative analysis in this study.

The study is structured as follows: Section 2 describes the workshop structure; Section 3 outlines the qualitative data collection and analysis methods used within the study; Section 4 presents the key workshop themes and outcomes; Section 5 considers future priorities for improved compound event and multi-hazard risk management; and Section 6 summarizes the findings.

2 | WORKSHOP STRUCTURE

The 2-day workshop held at the University of Strathclyde, Glasgow on 17–18 January 2023, brought together 42 participants who were invited due to their engagement in compound events and multi-hazard risk research, policy or practice. Invited participants' research interests and/or practice focused on a range of areas, including (re)-insurance, humanitarian aid, transport, water and energy distribution. Consequently, through presentations, breakout groups and wider discussions, the workshop facilitated dialogue among a diverse range of participants already grappling with the challenges of integrating compound event and multi-hazard thinking into a range of sectors.

Participants attended from across Europe and North America, representing institutions from 12 countries: Belgium, Finland, France, Germany, Greece, Iceland, Italy, the Netherlands, the Republic of Ireland, Switzerland, the United Kingdom and the United States. Approximately 57% of participants were researchers, including four early-career researchers; 24% were practitioners, and 19% held roles spanning research, policy and/or practice. While researchers were over-represented, many of them collaborate with practitioners in their work on topics such as infrastructure resilience and multi-hazard management, offering insights into research-practice collaboration. Several researchers also had previous experience in roles across science, policy and practice, contributing valuable insights into both practice and policy development.

The first day focused on developing a shared understanding of compound events and multi-hazards in the morning, followed by lessons learned from existing examples of science–policy–practice interactions in the afternoon. The second day aimed to improve compound event and multi-hazard risk management, introducing workshop attendees to research projects like the Horizon Europe-funded MYRIAD-EU and MEDiate projects, together with international networks and other initiatives such as Risk-KAN, providing opportunities to foster ongoing collaboration among workshop participants. Discussions also considered practical challenges and opportunities ahead in compound and multi-hazard risk management.

Each day featured keynote presentations, open panel discussions and breakout groups, offering diverse perspectives on the topics discussed. Speakers ranged from scientists working within compound events and/or multi-hazard research to a policymaker working within the United Nations (UN) and practitioners from transport and the (re)insurance sectors.

Breakout groups were aligned with the workshop's key topics (Figure 1), comprising members from the workshop organizing committee and a mix of researchers, policymakers and practitioners. The composition of the breakout groups changed between days to

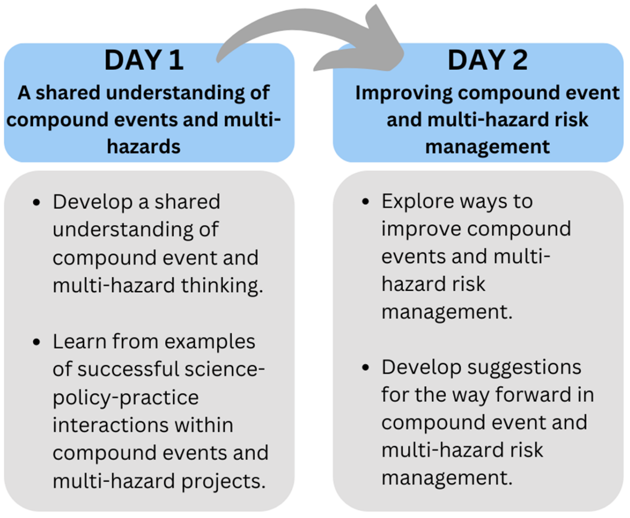

FIGURE 1 Schematic showing the key topic areas covered in presentations, panel discussions, and breakout groups across the 2 days of the workshop.

encourage broader discussion and networking. The groups were organized to promote diversity of discussion and idea sharing. After each of the 75-min breakout sessions, time was allocated for networking followed by 30 min of feedback, where high-level conclusions from each group were presented and discussed. The workshop concluded with an open discussion regarding opportunities within compound event and multi-hazard risk management going forward.

3 | METHODS

To extract the key themes, outcomes and recommendations from the workshop, multiple methods were employed to gather and analyse data. A workshop co-organizer first summarized the keynote presentations, interactive panel discussions and broader conversations held throughout the 2-day event, providing an initial overview of the key discussion points raised. During the breakout sessions, each group was assigned a rapporteur to take notes and summarize discussions. Additionally, workshop attendees were encouraged to record key ideas on A0 sheets of paper, which were shared back with other groups, facilitating further discussion.

A post-workshop survey was also conducted to allow participants to reflect on their experiences and provide further insights. 24 workshop attendees completed the post-workshop survey (57% of respondents). The survey questions enabled attendees to reflect on key discussion points raised throughout the workshop, such as factors that encourage successful science–policy–practice interaction, suggestions for improving compound event and multi-hazard risk management in policy and practice, and areas for future research and tool development within the compound event and multi-hazard space. The survey provided an opportunity for participants to share additional comments, including quieter voices from the workshop, promoting inclusivity in developing key themes, outcomes and workshop recommendations.

All data sources—including summary notes, breakout group notes and A0 sheets of paper, and post-workshop survey responses—were thematically analysed by a workshop co-organizer using Braun and Clarke (2013) six-step process: familiarization with the data, initial coding, theme identification, theme review, theme definition and providing evidence for the themes. All workshop attendees were invited to contribute to refining the key themes and recommendations identified through the thematic analysis process. This iterative process ensured that the study reflected the collective expertise and input of the participants enhancing the accuracy and inclusivity of this study.

4 | WORKSHOP THEMES AND OUTCOMES

Over the workshop, several key themes emerged for how the science and management of compound events and multi-hazard risks can be better integrated with policy and practice. These themes include: (1) developing a common language to communicate compound event and multi-hazard risks; (2) utilising case studies for improved communication surrounding compound events and multi-hazards; (3) promoting knowledge co-production of compound event and multi-hazard risk research to align with relevant real-world applications; (4) addressing complexity when analysing and communicating compound events and multi-hazard risks; (5) fostering science, policy, practice integration for compound event and multi-hazard research and risk management; and (6) centralising information for informed research, tools and frameworks related to compound event and multi-hazard risk management.

4.1 | Developing a common language

Central to multiple workshop discussions and presentations was the concern that it can be difficult to communicate and have clear discussions without the development of a common language surrounding compound event and multi-hazard risk management. Keynote speakers and breakout group discussions both explicitly and implicitly highlighted that there is a range of diverse, similar and overlapping terminology used to discuss compound events and multi-hazards, noting that this variation can lead to confusion. These opinions are echoed in existing reviews of multi-hazards and compound events that show how conflicting language is used to characterize these events (e.g., Ciurean et al., 2018; Gallina et al., 2016; Kappes et al., 2012; Tilloy et al., 2019).

The conflicting use of terminology relating to compound events and multi-hazards was evident throughout the literature shown and discussed during the workshop. UNDRR (2017), for example, uses the term 'cascading' to describe when one hazard is followed by another. In comparison, compound events research typically refers to one hazard followed by another as a 'temporally compounding' event, reserving 'cascading' for impacts such as 'cascading impacts' following an event (Zscheischler et al., 2020). The term 'hazard' also has multiple definitions across science, policy and practice. UNDRR (2020) defines a hazard as '…a process, phenomenon or human activity that may cause loss of life, injury or other health impacts, property damage, social and economic disruption or environmental degradation'. The UNDRR (2020) definition, or similar, is commonly used in policy and academic contexts. On the other hand, the (re)insurance industry offers various other definitions. According to Philp et al. (2019) a hazard is something that 'increases the likelihood of a peril occurring', while a 'peril' is defined as a cause of loss. Therefore, in the (re)insurance sector, a hazard is generally related to the probability of a peril, while in policy and academic contexts, it is more commonly linked to the potential cause of loss.

These examples highlight how differences in the use and perceived meaning(s) of terminology can lead to miscommunication and misunderstanding when discussing compound events and multi-hazards. However, pragmatic ways to foster a common language for compound event and multi-hazard thinking were explored during the workshop. For example, across science, policy and practice, we can encourage the development and uptake of consistent terminology across compound events and multi-hazards research, such as those outlined in key multi-lateral documents such as the UNDRR/ISC Sendai Hazard Definition and Classification Review Technical Report (Murray et al., 2020). The UNDRR/ISC Hazard Information Profiles (HIPs) were released in October 2021 as a supplement to the UNDRR-ISC Hazard Definition and Classification Review: Technical report, which was developed by UNDRR and the International Science Council (ISC) with the engagement of more than 800 partners from scientific institutions, including national scientific advisors, the research funding community and numerous international organizations (UNDRR, 2020). They facilitate the development of a common language as individuals and organizations can utilize consistent reference definitions. The HIPs will be updated for the Eighth session of the Global Platform for Disaster Risk Reduction (GP2025) to be held in June 2025 and are set to include, where appropriate, the multi-hazard context.

For individual projects, workshop discussions also highlighted that a common language and set of definitions should be agreed upon before project tasks begin. Discussions highlighted the importance of these clarifications occurring early within projects to reduce the chance of misunderstandings once tasks are assigned and actioned (Hillier & van Meeteren, 2024). It was also noted that it is important that all voices should be equally valued within this process, regardless of professional background or otherwise (Vincent et al., 2018).

Additionally, workshop discussions explored breaking down, or bridging, the silos between the different research communities to foster a common language within compound event and multi-hazard thinking. Although multiple scientists currently work across both sub-disciplines, different terminology is used to represent similar concepts in compound events and multi-hazard research. As a result, workshop attendees commented that cross-disciplinary discussions, through online or in-person workshops, meetings, and other networking events such as conferences, could lead to attempts to clarify terminology and foster a unified voice between compound events and multi-hazard research communities. These discussions could, in turn, lead to more clarity in communicating compound event and multi-hazard risks with practitioners and policymakers.

4.2 | Utilising case studies for improved communication

Discussions throughout the workshop highlighted multiple potential uses of case studies to assist in developing a shared understanding of compound event and multi-hazard risks. These include using case studies to support the communication of what compound events and multi-hazards are, highlighting the importance of understanding compound event and multi-hazard risk, and communicating how compound events and multi-hazards are likely to change in frequency and/or severity in the future.

Firstly, case studies were used throughout the workshop to facilitate discussions regarding key concepts, processes, definitions and terminology related to compound events and multi-hazards. For example, during the keynote presentation on compound and multi-hazard risk thinking, multivariate compound events (Figure 2a) were

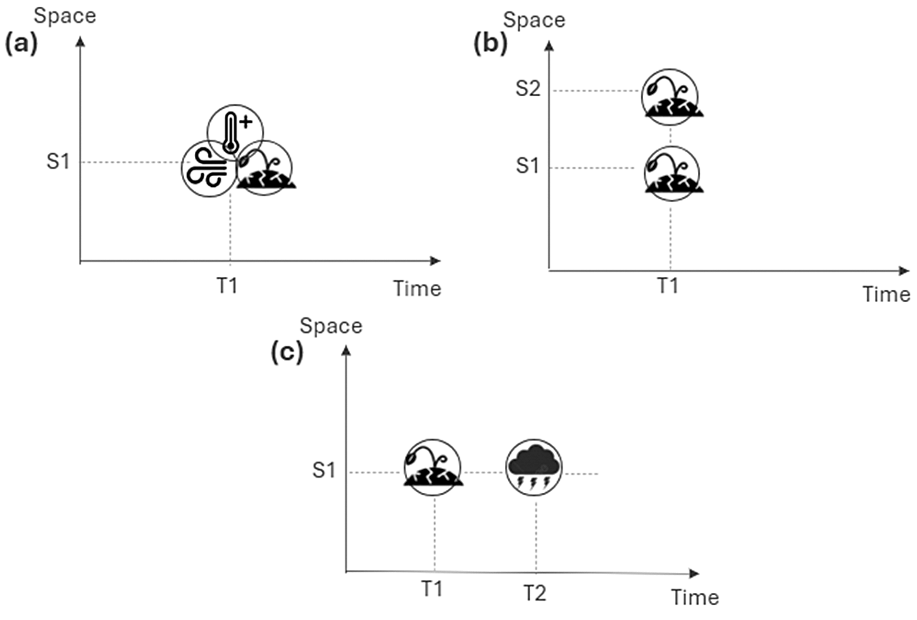

FIGURE 2 Time–space infographic showing examples of the different types of compound events and multi-hazards that either: (a) co-occur in the same space (Space 1 [S1]) and time (Time 1 [T1]), that is, multi-variate events; (b) occur in different spaces (S1 and Space 2 [S2]) but at the same time (T1), that is, spatially compounding; (c) occur in the same space (S1) but over different time-steps (T1 and Time 2 [T2]), that is, temporally compounding or preconditioned events.

exemplified via the Black Saturday wildfires case study in Australia (2009) (Dowdy et al., 2019). Here, high temperatures, low precipitation and high winds co-occurred simultaneously in time (T1) and space (S1), exacerbating wildfire propagation (Dowdy & Pepler, 2018). Spatially compounding events were introduced with a case study from 1983 (Anderson et al., 2019), where simultaneous (T1) breadbasket failures across multiple locations (S1, S2, etc.) including the United States, Brazil and Southern Africa (Figure 2b) impacted global food supplies, having knock-on effects on the affordability of commodities due to supply–demand relationships (Y. He et al., 2022; Lesk & Anderson, 2021). Finally, pre-conditioned and temporally compounding events were introduced with an example from the Horn of Africa exploring the exacerbated impacts of already drought-stricken communities (T1, S1) being hit by destructive floods in April 2018 (T2, S1), affecting water and food security, and human and ecosystem health (X. He & Sheffield, 2020; NASA, 2023) (Figure 2c). These case studies contextualized the compound events definitions presented in Table 1 and supported workshop attendees understanding of the complexity of the drivers and impacts of each event type. It was concluded that case studies can assist in both the science communication of what compound events and multi-hazards are and the wider need to understand compound event and multi-hazard risks.

Secondly, reclassifying historic extreme weather events that were initially classified as singular hazards was also suggested in the workshop to raise awareness of the potential impacts from compound and multi-hazard events. Since the workshop, ∼19% of disasters recorded in the EM-DAT global disaster database were re-classified as multi-hazard events, causing ∼59% of global economic losses from disasters (Lee et al., 2024). For example, 38 days of heavy rain in the United States in 1997, which was associated with a landslide in the EM-DAT database, was re-classified as a *pre-conditioned compound event* (see Table 1 for definition) (Lee et al., 2024). Behavioural psychology shows us that humans can have difficulties responding (rationally) to risks from events outside of their experiences, even if accurate quantitative information on a given risk is available (Shepherd et al., 2018). However, using episodic memory (reliving events) was highlighted as a possible tool to drive change in risk resilience (Schacter et al., 2007). It was therefore suggested that the reclassification of past events as case studies could trigger episodic memories and be a useful tool to raise awareness of the importance of the need to quantify compound and multi-hazard risk to reduce the chance of potentially underestimating future extreme weather event risk (van den Hurk et al., 2023). Other methods highlighted during the workshop to re-classify historic climatic events included rescuing historical, paper-based, climatological observations and combining these with modern reanalysis techniques to plausibly reconstruct past events (e.g., following Hawkins et al., 2023) and using spatial and temporal overlap of existing hazard footprints, as is the case for MYRIAD-HESA (Claassen et al., 2023). While reclassifying historic events does not necessarily consider how these events could change in the future, workshop attendees found that re-classified case studies can be a simple and effective tool to engage practitioners and policymakers with the potential consequences of not addressing compound and multi-hazard risk.

Like reclassifying past events, the storyline approach was proposed as a means of using episodic memory to attempt to drive change in compound event and multi-hazard risk resilience. The storylines approach takes known past extreme events and models how the impacts of these events could be perturbed or exacerbated with climate change (Goulart et al., 2024; Shepherd et al., 2018). For example, Goulart et al. (2024) created storylines from Hurricane Sandy, finding that for 1 m of sea level rise, the average flood volume increases 4.2 times, flooding more critical infrastructure than the original catastrophic event. Consequently, it was concluded that case studies can be used to both showcase impactful historic compound events and multi-hazards but also highlight how future extreme impacts may change as a result of climate change.

4.3 | Promoting knowledge co-production

The WAKOS Project presented during the workshop highlighted the benefits of applying transdisciplinary approaches to knowledge co-production in compound events research, using coastal communities across northern Germany as a case study. Knowledge co-production is an iterative, collaborative process that actively involves non-academic actors—such as practitioners, policy-makers and local communities—alongside researchers in framing research design, generating knowledge and applying that knowledge to address real-world challenges (Jahn et al., 2012; Klein, 2017; Norström et al., 2020; Pérez Jolles et al., 2022). This approach integrates diverse perspectives across the science–policy–practice interface to create knowledge and information to support decision-making (Lemos & Morehouse, 2005).

The iterative co-production process, as highlighted in the workshop, involves two interconnected domains: a practice-centred and a research-centred domain (see Figure 3). In the practice-centred domain, focus groups, interviews and transdisciplinary workshops help establish a shared understanding and identify key challenges. Researchers then synthesize these insights, sharing findings with practitioners for refinement to ensure alignment with their knowledge interests (Ruoslahti, 2019). Iterative exchanges between the two domains involve modifying research plans, developing initial findings and reflecting on results. Research outputs are continuously shared and adjusted to effectively address practitioner and policymaker needs, maintaining relevance and fostering actionable outcomes. Furthermore, embedding periodic evaluations further enhances responsiveness,

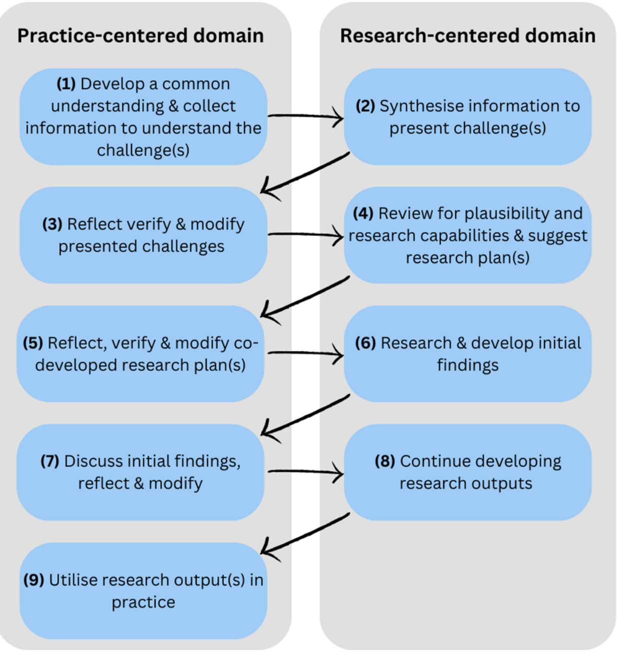

FIGURE 3 The iterative process of co-producing knowledge adapted from the WAKOS project presented within the workshop.

ensuring co-produced knowledge remains dynamic and impactful (Pérez Jolles et al., 2022; Ruoslahti, 2019).

Workshop attendees highlighted that by fostering collaboration across disciplines and integrating scientific, practitioner and local knowledge, the co-production process enhances the applicability and impact of research. Furthermore, they emphasized how this approach allows for the iterative refinement of risk frameworks and tools, increasing their effectiveness and longevity. Additionally, co-production not only bridges the gap between research and practice but also builds trust, promotes mutual learning and creates innovative, context-specific solutions. This co-production approach can help catalyse a step change in wider complex hazard risk management by integrating scientific knowledge with practitioner expertise, including local knowledge.

4.4 | Addressing complexity

During one of the breakout group sessions, workshop attendees were asked to outline perceived challenges of implementing compound event and multi-hazard risk analysis into practice and policy. One of the concerns raised by workshop attendees aligned with reports from civil contingency planners (e.g., Komendantova et al., 2014), highlighting that multi-hazard risk assessments could result in a more time-intensive and complex risk assessment process compared with single-risk procedures. For example, representatives from the transport sector noted the added complexity of extra variables when deciding whether to run a service (or not), and how to communicate this with the public. It was highlighted that this is particularly important where public safety is concerned, as clear communication is vital for decision-making and risk reduction (Fakhruddin et al., 2020). A further concern raised was that the data required may not be operationally available or used at present by incorporating additional complexity into the decision-making process. For example, transport representatives described the need for more live cameras to monitor vulnerable locations. In addition, participants acknowledged that limitations in data availability (e.g., a lack of measurements, coarse data resolution and restrictions in data sharing between organizations) can also hamper multi-hazard risk assessments.

To address the added complexity of integrating multi-hazard and compound event thinking into decision-making, several approaches were suggested by workshop attendees. One such approach was the development and use of binary decision diagrams, which were considered as a way to compute the risk associated with multiple variables. This method adds the required additional complexity to decision-making while still providing a binary 'go/no-go' outcome for operations (Minato, 2018). Binary outcomes may be useful for deciding whether to run a public service, for example, transport provision, that can be vulnerable to complex combinations of weather conditions.

Dynamic adaptive policy pathways (DAPP), which facilitate proactive planning and flexible adaptation over time in response to future uncertainties (Haasnoot et al., 2013), were also presented during the workshop. The DAPP approach involves anticipating circumstances that might fail, identifying actions that can be triggered if failures occur, and visualizing the sequences of actions over time in adaptation pathway maps (Carstens et al., 2019). The MYRIAD-EU project is co-developing a toolset with researchers and practitioners for forward-looking disaster risk management (DRM) pathways, including DAPP for Multi-Risk (DAPP-MR) (Schlumberger et al., 2022) and a framework for systemic and multi-hazard risk assessment and management (Hochrainer-Stigler et al., 2023). DAPP-MR is designed to gradually increase the complexity of decision-making in dynamic systems. First, adaptive strategies are developed within sectoral boundaries for each hazard of concern, then integrated per sector to account for interactions between the sectoral hazards/strategies, and ultimately integrated across sectoral boundaries to identify multi-risk strategies for the system. In a test case, DAPP-MR was applied in sectors including shipping, agriculture and urban housing to identify DRM pathways that mitigate future risks in climate change-related flooding and droughts. The test case showed that using a step-wise approach helped to identify the key interactions to focus on, which can result in trade-offs and synergies across strategies relevant for long-term planning (Schlumberger et al., 2024).

Many of the tools developed within research institutions are open-source and open-access, increasing the accessibility of these resources (e.g., Claassen et al., 2023; Stolte et al., 2024). Consequently, although incorporating compound event and multi-hazard risk thinking into practice may add complexity to decision-making, workshop attendees have highlighted that some tools may be available to assist in this process.

4.5 | Fostering science–policy–practice integration

The workshop attendees discussed how the compound event and multi-hazard risk research communities are tailoring their research agendas toward practical applications and uses such as disaster risk reduction (DRR) and climate change adaptation (van den Hurk et al., 2023; Ward et al., 2022). For example, van den Hurk et al. (2023) were shown as an example of moving toward providing practitioner guidance for incorporating compound thinking into multiple aspects of DRR such as early warning systems, infrastructure management and long-term planning. However, it can be challenging for practitioners and policymakers to find and gain access to literature since they generally do not have subscriptions to scientific journals, requiring payment for individual articles that are not open access. Additionally, the time required to read and synthesize the key messages from scientific papers adds another layer of difficulty in accessing up-to-date research.

Workshop discussions offered suggestions for how to address this challenge, highlighting the benefit of investing time in fostering science, policy and practice integration such as communicating research on generalist science communication platforms that are not behind paywalls such as Carbon Brief or The Conversation, and developing short blog posts (e.g., for CompoundNET) that can be circulated on professional social media platforms such as X or LinkedIn. These platforms highlight key outcomes of research and make findings more readily accessible and 'digestible'. Discussions also highlighted the benefit of researchers attending key industry conferences to present relevant research to practitioners outside of their existing network. Furthermore, publishing in practice-oriented journals that are read by practitioners could also make research outputs more accessible to industry groups.

The workshop also highlighted how knowledge exchange programmes, such as industry or policy placements, where scientists actively collaborate with practitioners and/or policymakers outside of academic institutions, and vice versa, are another potential pathway to foster science–policy–practice integration to introduce compound events and multi-hazard research into practice. Knowledge exchange programmes can be useful to foster the development of clear communication between scientists, practitioners and policymakers because technical terminology and wider information regarding day-to-day specific operations of industry or policy can be fed back to respective research institutions. Furthermore, knowledge exchange programmes can also enable practitioners and policymakers to understand the workload and incentive structures of researchers within academia to help initiate and nurture long-term, sustainable collaboration (Hillier et al., 2019). This process, however, takes careful collaboration and management. For example, compound events researchers working with the energy industry highlighted that it can be challenging to work with practitioners during the winter storm season because they can have a high workload managing the disruptions to the energy network during this period. However, it was also highlighted that there can be merit in harnessing the time after extreme weather events to promote research because the industry partners will likely have a renewed interest in managing hazards (Shepherd et al., 2018).

Established researchers who have worked collaboratively with industry partners highlighted the benefit of long-term relationships and secondments with industry to enact change within policy and/or practice. Furthermore, workshop attendees also noted that early career opportunities are beneficial in providing doctoral students with training and experiences as part of a collaboration between academic and non-academic organizations. These can provide early career scientists with opportunities to directly develop knowledge exchange skills that can continue to be used throughout their careers. It was agreed among the participants that investing financial resources and time into knowledge exchange programmes can enable researchers with expertise in compound event and multi-hazard research methods to be embedded in practice and/or policy, which could further facilitate both the development of a common language and the incorporation of compound event and multi-hazard risk quantification into practice.

4.6 | Centralizing information for informed research, tools and frameworks

A further challenge highlighted during the workshop was the limited awareness and uptake of existing compound event and multi-hazard frameworks and guidelines in practice. Natural hazard risk frameworks (e.g., Ciurean et al., 2013; Cremen et al., 2022; Eiser et al., 2012) assist in assessing and understanding compound events and multi-hazard physical risk (Hillier & van Meeteren, 2024). There are already a range of frameworks and guidelines available in the literature (e.g., Hochrainer-Stigler et al., 2023; Bevacqua et al., 2023) or are in development, yet it was remarked that their uptake by practitioners remains low. Ongoing projects such as MEDiate, MYRIAD-EU, Paratus and WAKOS are, however, actively working with practitioners to co-develop tools that can enhance the assessment of multi-hazard and compound event risks, which may aid their adoption and uptake.

The workshop emphasized that stronger signposting of existing resources would help scientists, practitioners and policymakers appropriately select and apply the most relevant framework or methodological approach for their specific needs, potentially through a designated website or wiki platform such as the Disaster Risk Gateway. Developed as part of the MYRIAD-EU project, the Disaster Risk Gateway is an open-access, editable wiki that supports the sharing of approaches for understanding, analysing and managing multi-hazard risks. For example, it includes a five-step multi-hazard framework by De Angeli et al. (2022) for spatial–temporal impact analysis, applied in a case study in the Po Valley, Italy, aimed at enhancing disaster risk management and integrating multi-hazard considerations into international guidelines.

The workshop attendees also suggested regular workshops and conference sessions focused on frameworks and tools for managing compound and multi-hazard events, bridging both academia and industry. For instance, the 3rd International Conference on Natural Hazards and Risks in a Changing World, held in Amsterdam 2024, included a session on 'Demonstration of Tools and Services' focusing on multi-hazard software tools and methods. The session was structured as a hands-on science fair, allowing attendees to gain practical insights and learn from past challenges and current success stories in developing tools for compound event and multi-hazard management.

Workshop discussions also highlighted that logic maps, such as monitoring maps for the United Kingdom (Climate Change Committee, 2023), can support iterative improvements of compound event and multi-hazard risk management processes. By understanding the high-level goals of a sector or system, it is then possible to work backwards to the required outcomes, identify key enablers and barriers to delivery, and consider what actions, or policies, may facilitate the delivery. Additionally, presentations and discussions noted that some frameworks (e.g., Bevacqua et al., 2021; Hillier & Dixon, 2020) typically include detail on physical processes but often omit a quantification of the impacts or implications (Hillier & van Meeteren, 2024). Consequently, Co-RISK, which is an accessible toolkit for co-creating joint collaborative projects between universities and industry, was presented to equip participants with knowledge and guidance to prepare their own tailored and detailed frameworks for natural hazard risk management, spanning from climate knowledge right through to implications (Hillier & van Meeteren, 2024). It was concluded that by understanding the key enablers and barriers to the delivery of compound events and multi-hazard risk policies, and by considering the tangible implications of implementing different management techniques, scientists, practitioners and policymakers may be more likely to implement compound event and multi-hazard risk management into policy and practice.

5 | FUTURE PRIORITIES

The workshop discussions generated multiple actionable recommendations aimed at improving the management of compound and multi-hazard risks in policy and practice. These recommendations, which are summarized in Table 2, ranged from standardizing terminology by using key multi-lateral documents to facilitate a unified understanding of compound and multi-hazard risks; to promoting initiatives that bring together researchers, practitioners and policymakers to collaboratively co-produce frameworks and tools for handling multi-hazard risks; to using real-world case studies to demonstrate the impacts of compound events; and utilising useful tools such as the UNDRR/ISC Hazard Information Profiles (due for update by June 2025), or platforms like the Disaster Risk Gateway to serve as a repository for multi-hazard research, tools and methods, facilitating easy access for practitioners, researchers and policymakers.

Building on the discussions drawn from across the workshop, the final session of the workshop produced a synthesized list of high-level future priorities for addressing compound events and multi-hazard risks which include: (1) raising awareness and improving communication; (2) supporting implementation in practice; and (3) improving engagement and transdisciplinary approaches to knowledge co-production (Figure 4). Reiterated priorities included promoting research methods like storylines to effectively communicate changes in the frequency and intensity of complex risks; encouraging

TABLE 2 Key suggestions to improve compound and multi-hazard risk management raised during the workshop.

Key suggestions raised during the workshop
3.1 Developing a common language
• Encourage the development and uptake of consistent terminology across compound events and multi-hazards research, such as those outlined in key multilateral documents.
• Work towards breaking down, or bridging, silos between different research communities, fostering a common language within compound event and multi-hazard thinking.
3.2 Utilising case studies for improved communication
• Use case studies to support the communication of what compound events and multi-hazards are and demonstrate the impacts of compound events and multi-hazards in the 'real-world'.
• Utilize storyline case studies to explore how compound event and multi-hazard impacts may change in severity and/or frequency with climate change.
3.3 Promoting knowledge co-production
• Promote co-production of compound event and multi-hazard risk research, frameworks and tools, increasing the effectiveness and longevity of wider complex hazard and risk management.
3.4 Addressing complexity
• Consider developing binary decision diagrams, adding required additional complexity into decision-making while still providing a binary 'go/no-go' outcome for operations.
• Use dynamic adaptive policy pathways (DAPP) that enables users to proactively plan for flexible adaptation over time in response to how the future unfolds.
3.5 *Fostering science–policy–practice integration*
• Invest time in communicating research on generalist science communication platforms.
• Encourage knowledge exchange programmes, such as industry or policy placements, where scientists collaborate with practitioners and/or policymakers outside of academic institutions.
• Promote early career opportunities providing doctoral students with training and experiences as part of a collaboration between academic and non-academic organizations.
3.6 Centralising information for informed research, tools and frameworks
• Use a designated website or wiki platform to signpost existing resources for compound event and multi-hazard research and management.
• Organize regular workshops focused on frameworks and tools for managing compound and multi-hazard events, bridging both academia and industry.

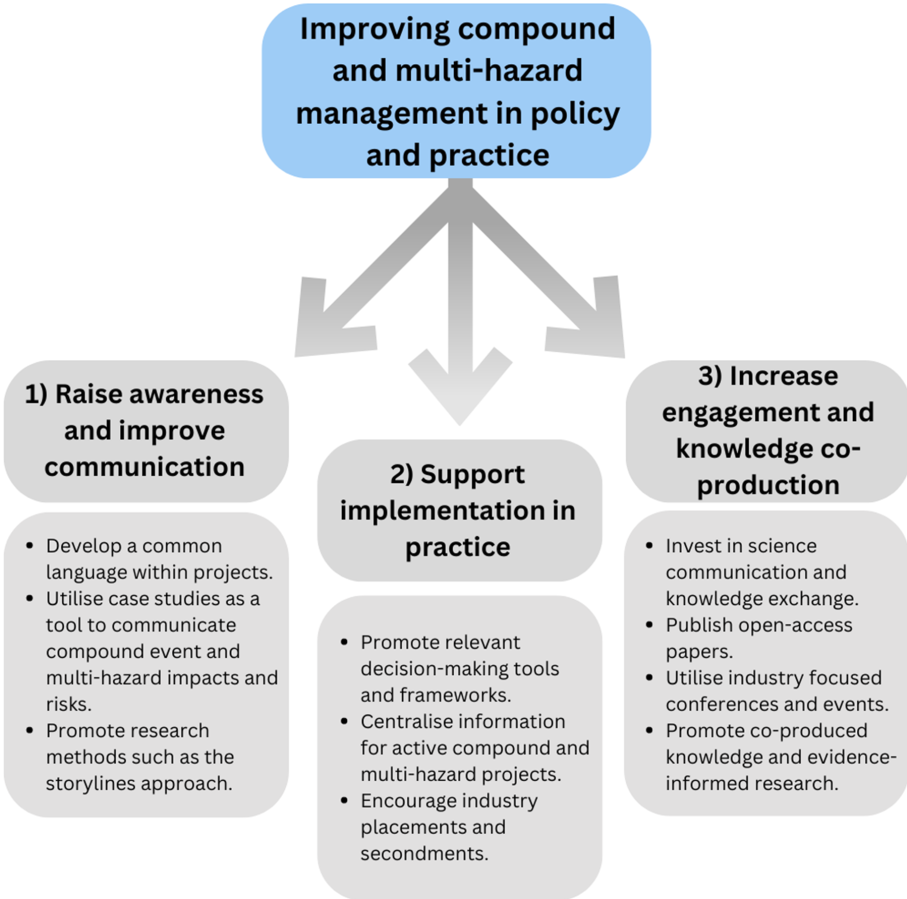

FIGURE 4 Schematic summarizing the identified high-level priorities for how to improve compound event and multi-hazard risk management in policy and practice.

industry placements and secondments to embed researchers in policy and practice, thereby fostering shared learning; and enhancing research dissemination through industry-focused conferences, events and open-access publications.

Ongoing multi-hazard projects such as MEDiate, MYRIAD-EU and Paratus, supported by internationally coordinated efforts, are already proactively addressing these priorities, building a collaborative international community focused on compound event and multi-hazard risks. Initiatives like the Risk-KAN platform, with its compound events and impacts working group, are also providing an open platform for communities across disciplines to exchange information, knowledge and data. Importantly, many of these projects and initiatives now involve practitioners and policymakers and are adopting knowledge co-production approaches. While much work remains to be done, by bringing disciplines together, this workshop has highlighted ways to synergistically address and implement strategies related to compound event and multi-hazard risk management into policy and practice, ultimately leading to improved risk management outcomes.

6 | SUMMARY

Despite advances made in recent decades, risk is still often assessed and managed from a siloed perspective, without adequately considering the interactions and interdependencies between hazards and sectors. To help overcome this challenge, a two-day workshop in Glasgow in 2023 uniquely brought together practitioners, policymakers and researchers to share knowledge, experiences and learnings and provide suggestions for how to improve the management of compound and multi-hazard risks in policy and practice. A range of themes and opportunities emerged from the workshop, highlighting the need for increased engagement with and collaboration between multiple scientific disciplines involving practitioners and policymakers. There was a clearly identified desire for compound events and multi-hazards research to develop a common language to reduce overlapping terminology and definitions, ensuring awareness and communication of key concepts is consistent. Additionally, a range of activities, summarized through case studies, can lead to improved uptake and implementation of compound events and multi-hazard approaches. Overall, by working together, this workshop has highlighted ways to synergistically improve the management of compound and multi-hazard risks across science, policy and practice.

AUTHOR CONTRIBUTIONS

Lou Brett: Conceptualization; methodology; investigation; formal analysis; data curation; visualization; project administration; writing – original draft; writing – review and editing. **Hannah C. Bloomfield:** Conceptualization; supervision; writing – review and editing; methodology. **Anna Bradley:** Writing – review and editing. **Thibault Calvet:** Writing – review and editing. **Adrian Champion:** Writing – review and editing. **Silvia De Angeli:** Writing – review and editing. **Marleen C. de Ruiter:** Writing – review and editing; visualization. **Selma B. Guerreiro:** Writing – review and editing. **John Hillier:** Writing – review and editing. **David Jaroszweski:** Writing – review and editing. **Bahareh Kamranzad:** Writing – review and editing. **Minna M. Keinänen-Toivola:** Project administration; writing – review and editing. **Kai Kornhuber:** Writing – review and editing. **Katharina Küpfer:** Writing – review and editing. **Colin Manning:** Writing – review and editing. **Kanzis Mattu:** Writing – review and editing. **Ellie Murtagh:** Writing – review and editing. **Virginia Murray:** Writing – review and editing. **Áine Ní Bhreasail:** Writing – review and editing. **Fiachra O'Loughlin:** Project administration; writing – review and editing. **Chris Parker:** Writing – review and editing. **Maria Pregnolato:** Writing – review and editing. **Alexandre M. Ramos:** Writing – review and editing. **Julius Schlumberger:** Writing – review and editing. **Dimitra Theochari:** Writing – review and editing; project administration. **Philip Ward:** Writing – review and editing; project administration; funding acquisition. **Anke Wessels:** Writing – review and editing. **Christopher J. White:** Writing – review and editing; project administration; methodology; conceptualization; supervision.

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The authors declare no conflict of interests.

DATA AVAILABILITY STATEMENT

Data sharing is not applicable to this article as no new data were created or analyzed in this study.

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