A Framework for Global Science

in Support of

Risk-informed Sustainable Development and Planetary Health

International Science Council

IRDR
Integrated Research on Disaster Risk

UNDRR
UN Office for Disaster Risk Reduction

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“At no point in human history have we faced such an array of both familiar and unfamiliar risks, interacting in a hyperconnected, rapidly changing world.

New risks and correlations are emerging. Decades-old projections about climate change have come true much sooner than expected. With that come changes in the intensity and frequency of hazards.

Risk really is systemic, and requires concerted and urgent effort to reduce it in integrated and innovative ways.”

Mami Mizutori, Special Representative of the United Nations Secretary General for Disaster Risk Reduction, UNDRR Global Assessment Report on Disaster Risk Reduction 2019

Preface

In 2019, the International Science Council (ISC) and the United Nations Office for Disaster Risk Reduction (UNDRR) invited the Integrated Research for Disaster Risk program (IRDR) to lead on the development of a global research agenda for risk-informed development to guide impactful international disaster risk research and its funding. Since then, the COVID-19 pandemic has laid bare the integrated nature of human development and planetary health, brought renewed urgency to tackling the underlying drivers of risks at different scales, and demonstrated the vital role of science in coping with and preventing future crises.

This document takes stock of recent developments in disaster risk science and provides a compelling set of directions for research and scientific collaboration for a more holistic and collaborative approach to understanding and managing risks. It challenges silos in science and in society and the notion that social, ecological, economic and technological systems can be understood in isolation from one another, and advocates for an increased focus on people.

The consultation process has sought to engage widely across the scientific community working on disaster risk, climate change, sustainability, and development. It also engaged with indigenous scholars, and actors in the private sector and civil society. We would like to express our gratitude to all who have contributed to this process, shared their insights and who wish to continue the conversation as we work as a community towards its implementation. We would especially like to thank Prof. John Handmer and Prof. Coleen Vogel for their leadership as co-chairs, Dr Ben Payne for coordinating this process, and the IRDR programme for its extensive support and contributions.

UNDRR and the ISC are committed to engage widely with scientists, research funders, decision-makers in the public and private sectors to build momentum towards the trans-disciplinary risk science that we need to support bold action towards a safer world. This document provides a very valuable input into the process initiated by the two organisations to guide the next decade of international research on disaster risk.

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The emerging global risk landscape of a pandemic, dramatic changes to climate and biodiversity, social and financial crises, severe degradation of the environment and ecosystem services, digitalization and hyperconnectivity, inequalities and vulnerabilities poses new challenges for disaster risk reduction (DRR) and its associated areas of climate change adaptation and risk reduction through the Sustainable Development Goals (SDGs). The trend is for more severe and complex impacts with increasing global concern about and acknowledgement of systemic, compound and cascading risks and impacts. Rapid political, social and technological developments in addition to planetary change are contributing to this shifting landscape. The risks seem existential, posing a threat to many communities and livelihoods and, ultimately, to humanity's existence. The arrival of the Anthropocene era, with humanity as the major force of planetary change, is clear recognition of our situation and the threat of earth-system tipping points, planetary boundaries and biodiversity and ecosystem collapse (Folke et al, 2021).

These challenges are daunting but, because they are driven by development processes, they are also amenable to policy and local action. To help meet these challenges by supporting ambitious development action, DRR needs to be reimagined with much more robust and broader reach and actors working collaboratively across sectors, disciplines and types of knowledge. There is an overriding need to go well beyond siloed thinking and "business as usual" if we are to address these closely linked global imperatives successfully. For risk reduction, the need now is to maximize the effect that risk science can have in changing the future direction towards better outcomes. To achieve this, risk scientists and knowledge holders need to collaborate and reach well beyond their traditional networks to those in policy and practice and to those in the cognate and synergistic areas of climate change and the SDGs. Further evidence is hardly needed, but the complex systemic risk presented by the COVID-19 pandemic highlights global vulnerabilities, the strengths and weaknesses of global risk governance and the challenges posed for risk communication in a world with numerous conflicting information sources and what is often a partisan political environment. Pandemic recovery planning has included increased public and political acknowledgment of the centrality of social vulnerability reduction as a strategy for building resilience to multiple and as yet unknown risks. This reinforces the need for a different approach.

The agenda outlined in this document sets out some important areas where additional actionable knowledge would likely result in reduced risk and vulnerabilities and improved human well-being. It is intended for those working in DRR and the related areas of global risk, climate change adaptation and development. It is relevant to those interested in improving current DRR practices as well as those who see the need for more fundamental change.

The agenda was commissioned by the International Science Council (ISC) and United Nations Office for Disaster Risk Reduction (UNDRR) and its development has been led by the Integrated Research on Risk (IRDR) programme. From the outset, the emphasis has been on a collaborative, co-design approach with wide, iterative consultation. The agenda engages with and reflects the priorities and interests of groups well beyond traditional DRR research and practice, with the aim of building the evidence base necessary for risk-informed decision-making in all geographical contexts and sectors and at all levels. To support additional engagement on the agenda, a number of specialist groups were assembled, with a focus on indigenous knowledge and the private sector, among others.

The research priorities

The priorities that were identified in the development of the agenda highlight that, although much research and progress has been achieved in DRR over the past decade, much of that knowledge is unused due to a lack of effective collaboration between all types of knowledge holders, policy and practice. Silos and significant disconnections remain within and between disciplines, as well as between knowledge producers and potential knowledge users. This lack of integration and transdisciplinary focus has reduced the impact of disaster risk science and its capacity to help address macrosocietal challenges such as alleviating poverty and reducing vulnerability and exposure to all forms of disaster risk.

Based on iterative consultations with stakeholders across a wide range of interests, the following nine priority areas were identified. These can each apply across a range of contexts and scales, from global to local and rural to densely urbanized. There is considerable overlap between the priorities, and some priorities are cross-cutting applying to most, if not all, of the other priorities.

1. Address today's complex global risk landscape: How disaster risk reduction can accelerate the transition to a peaceful, safer, equitable, sustainable world within the context of DRR

Key question: how can research inspire better understanding of the complex interconnections of systemic, compound and cascading risks and impacts, and their connections with vulnerability and exposure.

Potential early result: how can comprehensive risk assessments, that include global threats, systemic impacts, inequalities and vulnerabilities, be undertaken with local communities?

2. Address inequalities, injustices and marginalization

Key question: how can risk science and knowledge support the most marginalized people and communities to ensure that "no one is left behind", as part of ensuring inclusive justice and equity across humanity?

Potential early result: how can risk science best support the development and adoption of tools that enable practitioners to consider risk and its distributional impacts when defining development strategies?

3. Enable transformative governance and action

Key question: how can transdisciplinary science and knowledge transform access to and participation in governance structures and actions to reduce disaster risk?

Risk reduction, climate adaptation and the achievement of the SDGs are intrinsically linked.

Potential early result: what is known across science and other sources of knowledge including the private sector, about integrative governance and action for DRR, climate change adaptation and the SDGs?

4. Understand the implications of new thinking on hazards

Key question: how can we best identify and understand new forms of, or newly common extreme forms of, hazards as well as their intersection with other vulnerabilities and hazards?

The ISC/UNDRR 2020 *Hazards Definition and Classification Review* identifies over 300 hazards, many of which are new to DRR.

Potential early result: how to develop and put into action impact-based warnings that draw on multiple disciplines and agencies as well as the private sector and civil society?

5. Harness technologies, data and knowledge for risk reduction

Key question: what are the factors that impede or support emerging technologies in achieving their promise of risk reduction, rather than creating or shifting risk; and how can the technologies be better used to support the SDGs and risk reduction?

Rapid technological advances are driving major changes in our lives and have the potential to contribute to all aspects of risk reduction and disaster management. This priority area seeks to inspire research that takes the opportunities to maximize positive impact.

Potential early result: what factors impede or support technologies in achieving their promise of inclusive risk reduction, rather than shifting or creating risk?

6. Support regional and national science and knowledge for policy and action

Key question: what are the research priorities of different global regions? Regions have distinct mixes of hazards, exposures and vulnerabilities, which are influenced by complex root causes, interdependencies, capacities and governance structures.

Potential early result: how can regional research leadership utilize substantive global research in national and local contexts to drive inclusive risk reduction to reduce vulnerability and risk in future development?

7. Support just and equitable transitions, adaptation and risk reduction

Key question: how can a just and equitable transition to a sustainable less risky world be ensured?

Potential early result: how can relocations driven by transition, adaptation or disaster risk reduction be undertaken to minimize the impact on livelihoods and identity?

8. Measurement to help drive progress

Key question: what needs to be measured and how can measurement be designed to incentivize improved risk knowledge and risk reduction?

Potential early result: how can we best measure progress with reducing risk in development through addressing priority area 2, drawing on current knowledge and experience?

9. Foster interdisciplinary and multi-stakeholder collaboration

Key question: why is so much knowledge apparently unused? There are many areas where it is well applied which could provide starting points for learning and change.

Potential early result: what are the most effective ways of developing and supporting networks of practice and knowledge to enable exchange and development of ideas and interaction with those in policy and practice?

Pathways to impact and transformative change

The agenda concludes with a non-prescriptive section on implementation. In summary, this research agenda is intended to help connect knowledge, policy and practice, foster innovative thinking and encourage greater research investment in the priority areas identified. The agenda can also help to connect all knowledge holders, including scientists, funders, the private sector, policymakers and practitioners across disciplines and sectors to encourage new types of partnerships across traditional silos to find new approaches to addressing today's global challenges. This document represents the start of a discussion to encourage and enhance knowledge-to-action outcomes across the wide dimensions of risk science, represented by the Sendai Framework for DRR, Paris Agreement on climate change and the SDGs. To achieve this transformative democratization of science, it advocates networks and communities of practice, with an "open science" approach.

Introduction

Solutions to the combined risks and crises facing humanity and the planet can be found through the collaborative efforts made to drive change through utilizing all relevant knowledge and policy resources, including new knowledge acquired from the research set out in this document. Many of the major global crises and threats are well known: the COVID-19 pandemic, climate change, ecosystem and biodiversity collapse and financially and socially induced risks. Less well known are the day-to-day crises and risks that affect much of the globe as a result of inequalities and vulnerabilities, which are often exacerbated by globalization, digitalization, severe environmental degradation and unsustainable development. Disaster risk has therefore come to occupy a central place in global development, with science needing to be more effective, innovative and collaborative in order to address intensifying risk exposure and vulnerability in the global context. Coherence between the 2015 Sendai Framework for Disaster Risk Reduction and parallel major United Nations frameworks concerned with addressing risks – such as the Sustainable Development Goals (SDGs), Paris Agreement on climate change, New Urban Agenda, Addis Ababa Action Agenda on Financing for development and Agenda for Humanity – will also assist in addressing inequalities and instilling risk reduction as a critical function of development.

The global risk landscape, and human responses to risk, are therefore undergoing rapid and profound changes (Steffen et al. 2015). Recognition of the Anthropocene era, in which humanity is the major force of planetary change, is also an acknowledgement of the urgency of the situation (Folke et al. 2021). The global trend is for more severe and complex impacts, which is reflected in increasing concern about and acknowledgement of complex and systemic risks whose impacts cascade through social, economic and environmental systems. This situation underlines the growing interconnectivity and interdependence across and within human, technological and biophysical systems and highlights the potential for physical and socioeconomic tipping points that could have significant systemic effects.

The COVID-19 pandemic not only is a systemic risk (Cook and Penzini, 2020; Rizwan et al 2020), but lacks clear geographical and temporal boundaries. The virus and the response that it has engendered highlight the complexity of global risk and the fragility of human systems, including the weakness of global risk governance, which is often disconnected from local risk realities and governance efforts. It has also highlighted the challenges posed by an environment awash with misinformation and a multiplicity of diverse information sources. Existing approaches to thinking about and managing risk have been overwhelmed by the pandemic's systemic nature, which shows how global risks can fundamentally alter how humanity lives, even if not threatening our existence.

Rapid political, social and technological developments, in addition to climate change, are contributing to the shifting landscape. There is an overriding need to go well beyond siloed thinking and the desire to preserve the status quo if these closely linked global imperatives are to be addressed successfully. Returning to, and supporting, the status quo is what many disaster risk reduction (DRR) and resilience approaches aim to achieve; however, while this can be very successful in protecting lives, livelihoods and assets, it can also entrench existing vulnerabilities and other risk drivers and limit the potential for transformation.

The challenges are daunting but, because development processes drive them, they are also amenable to policy and local action. It is worth noting that almost half the urban infrastructure anticipated for 2050 is yet to be built; further, new open and integrated data systems will allow complex challenges to be resolved. Much COVID-19 recovery planning incudes increased public and political acknowledgment of the centrality of reducing social vulnerability as a strategy for building resilience to multiple, and as yet unknown, risks. Realizing these opportunities will require

DRR to be reimagined, extending it from a singular focus on major events to a proactive, inclusive and risk-based approach that incorporates climate adaptation, vulnerabilities and development in order to address the causes as well as consequences of disaster. Risk science should motivate the search for opportunities and solutions, building on the success of contemporary DRR with its major reductions in the human toll of disasters through warning systems, emergency management and enhanced preparedness.

To identify knowledge gaps and priorities and to build the evidence base needed for risk-informed decision-making in all geographical contexts and sectors and at all scales, the agenda developed here seeks to engage with and reflect the priorities and interests of groups beyond traditional DRR research and practice. The consultative process, which is set out in section 2, below, and in more detail in Appendix 1, included disaster risk scientists, researchers, academics, and technical institutions in both the public and private sectors, traditional and indigenous knowledge holders, as well as funders of research and practice. The agenda calls for an integrated, inclusive, systemic approach to risk reduction that gives prominence to the issues of justice and equity. The emerging collaborative, integrative approaches of "One Health" and "Planetary Health" (The Lancet, 2015), which emphasize the integrative nature of people, plants, animals and their shared environment, offer a possible pathway. An integrated approach of this type is seen as an important step in reducing the risk of future zoonotic pandemics (Mackenzie and Jeggo, 2019).

The agenda helps to identify the needs of stakeholders and actors working at country, regional and international levels and is, in turn, itself guided by those needs. It will also guide the development of research to address those needs and to help solve broader issues. The agenda's audience is all those engaged in DRR and related risk, resilience, adaptation and development action as practitioners, policymakers, researchers and knowledge holders. This extends to those working on all aspects of vulnerability and to those funding research and practice for risk and development, as well as the associated areas of human and planetary change.

This document sets out the detailed rationale and process for developing the agenda, a review of the trends in and status of disaster risk knowledge, the research priorities comprising the agenda and an implementation guide (see figure 1.1). Additional detail and supporting material can be found in the appendices to this document. The agenda does not have a set timespan and is intended to serve as a framework to guide and inspire, rather than prescribe. It will be a reference document for communities of practice to draw on, debate and adapt to contexts and priorities. The agenda's implementation is in the hands of all disaster risk-related actors and stakeholders across the world, and its success will depend on transdisciplinary and multisectoral collaboration at all levels.

Figure 1.1 The three major components of the risk research agenda

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Developing the research agenda

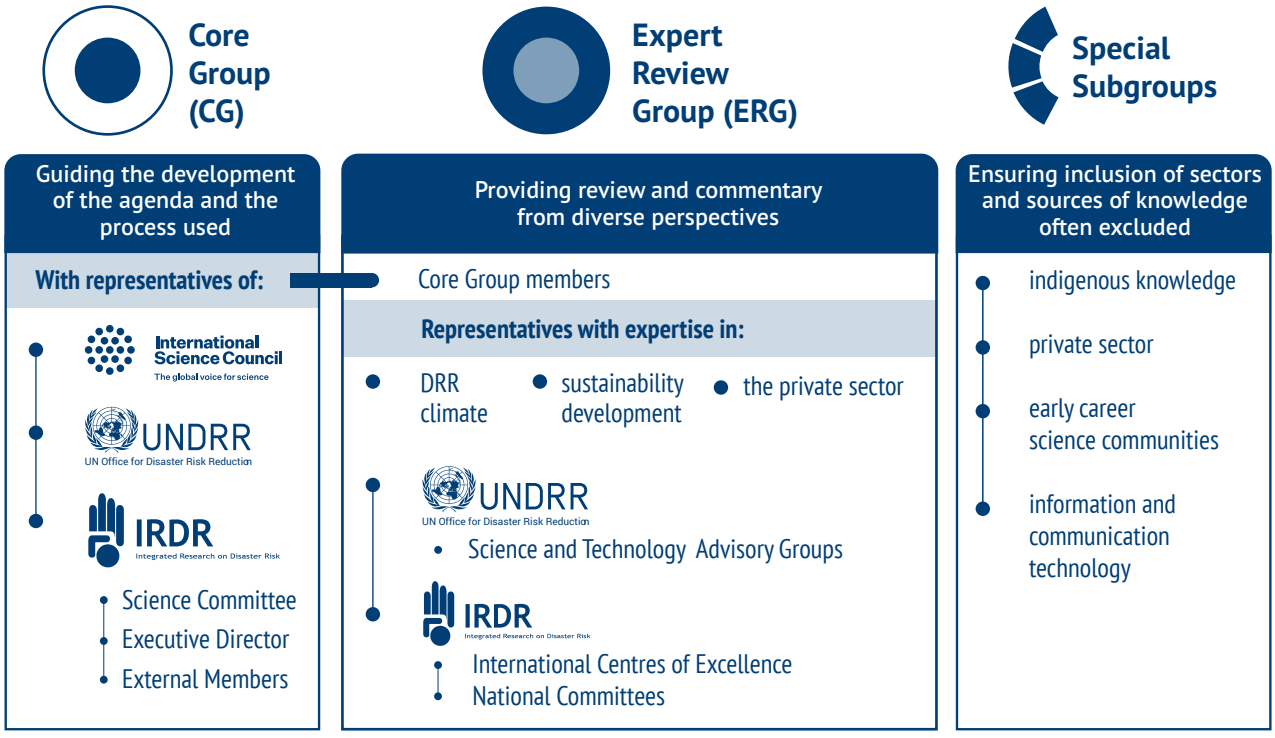
2.1 Organization

The agenda was commissioned by the International Science Council (ISC) and United Nations Office for Disaster Risk Reduction (UNDRR), with the Integrated Research on Disaster Risk (IRDR) programme leading its development. From the outset, the emphasis has been on a collaborative, co-design approach with wide consultation.

Two groups were established to support the development of the agenda (see appendices 1 and 2 for details of the groups and consultation process): a Core Group and Expert Review Group (see figure 2.1). The Core Group is responsible for guiding the development of the agenda and the process used, while the Expert Review Group provides review and commentary from diverse perspectives. Membership of the Core Group consists of representatives of the ISC, UNDRR, the IRDR Scientific Committee, IRDR Executive Director and other IRDR and external members. The Expert Review Group consists of Core Group members and representatives with expertise in DRR, climate, sustainability, development and the private sector, as well as representatives of the UNDRR Science and Technology Advisory Groups. This expertise is augmented by the IRDR International Centres of Excellence and National Committees.

To ensure the inclusion of sectors and sources of knowledge that are often excluded, specialist sub-groups on, inter alia, indigenous knowledge and the private sector were established to support the Expert Review Group.

Figure 2.1 Organizational structure and process for development of the agenda



2.2 Process

The agenda was developed iteratively between late 2019 and mid-2021, through multiple consultations with, and input from, the groups mentioned previously. The formal iterations of the consultation are set out in appendix 1. The stages of the process can be summarized as follows (see also figure 2.2):

1. Surveys of the IRDR community (IRDR Scientific Committee, International Programme Office, International Centres of Excellence, National Committees) to identify key literature sources and establish the initial draft research priorities.
2. Review and analysis of the scientific literature (see appendix 3) to establish the current state of research and gaps and needs across DRR, resilience and other themes.
3. Iterative consultations with the IRDR community and 20-member Core Group, with frequent interactions including one-to-one discussions. The 45-member ERG provided strategic input early in the process and then detailed feedback and commentary on a complete draft of the agenda in April 2021. The draft version of the agenda was also available on the ISC webpage, along with a survey on the draft agenda, which returned 57 responses. Specialist groups consisting of indigenous and private sector representatives were established and provided valuable input.
4. Presentations and discussions at IRDR Science Committee meetings and other meetings, including the Asia Pacific Science and Technology Conference for Disaster Risk Reduction.
5. A major session of 2021 IRDR International Conference was dedicated to the agenda; this and other conference sessions provided commentary on the draft agenda. It was also the focus of a number of regional meetings held before the IRDR Conference.
6. A pre-final draft of the agenda was presented for endorsement at the 2021 IRDR Conference in June 2021.

2.3 Principles and key questions guiding agenda development

The development of the agenda has been informed by a number of principles. These were developed and agreed by the Core Group to articulate and frame the approach to be taken. The objectives of the agenda are as follows:

1. Be responsive to the new global risk, development and planetary health contexts and actively support coherence across major United Nations agreements on DRR, climate change, planetary health and the SDGs.
2. Take a systemic and multi-risk perspective, capturing emerging, dynamic, complex and cascading risks, and give attention to the appropriate response space.
3. Focus on policy relevance and outcomes.
4. Inform processes to collaboratively implement and achieve the Sendai Framework for DRR, the Paris Agreement on climate change, and the SDG targets, as part of the 2030 Agenda for Sustainable Development.
5. Be consultative and collaborative across disciplines, domains and stakeholder and actor groups, in line with the Sendai Framework principle of transdisciplinary collaboration.
6. Recognize DRR as essential to the development process and improved human well-being.
7. Engage with traditional and other forms of knowledge and, where practicable, promote co-production of knowledge.
8. Promote ethical, inclusive approaches to research and research results.
9. Consider how research is funded and how the results could be implemented.
10. Go from theory to practice by focusing on impact for both policy and practice.
11. Be flexible and adaptable to changing circumstances.

In summary, the principles focus on encompassing global risk and systemic and emerging risks; advancing coherence across the substantive areas encompassed by major global agreements, including the SDGs, on DRR, climate and other critical issues as part of the 2030 Agenda; emphasising collaboration and being inclusive of disciplines, regions and forms of knowledge; promoting ethical and inclusive forms of knowledge and research; being relevant to policy and practice and flexible and adaptable to changing circumstances.

RATIONALE

3

Context and rationale for a new agenda

Why is a new global risk science research agenda needed, rather than amending the present settings of risk science networks, platforms and research programmes? The rationale for a new risk science research agenda is found in the emerging global risk landscape, changes in thinking about disasters and risk and the need for coherence across the areas encompassed by major global agreements relevant to the reduction of risks and vulnerabilities (see appendix 3).

Figure 3.1 will outline the key themes of this section

3.1 The global risk landscape

The global risk landscape is undergoing rapid and profound changes across DRR, climate change and sustainable development. The current trend is one of more severe and complex impacts and there is increasing concern about and acknowledgement of complex, cascading and systemic risks. Some of the more obvious signs of these changes are the unprecedented climate and weather shocks and stresses associated with economic and humanitarian crises, which are potentially driving conflicts, internal displacement and large-scale international movements of people, as well as the crises precipitated by accelerated warming in polar regions and major changes to ocean ecosystems.

The COVID-19 pandemic is not only a cascading and systemic risk, but is itself framed in many different ways (Wicke and Bolognesi, 2020). Both the virus and response to it highlight the complexity of global risk as it plays out in multiple geographical contexts over time. In keeping with many high-profile risks, COVID-19 is portrayed in mainstream media alternatively as war, a fairness issue, a geopolitical issue, a public health issue and about the competence of politicians, the public sector and leadership, among other framings. At different times and from different perspectives, these multiple perspectives and contextual understandings of risk may all be reasonable.

As the example of COVID-19 shows, this rapidly evolving landscape is framed in different ways and characterized by multiple definitions that vary by sector, discipline, circumstance and worldview; however, even within and across disciplines there can be distinctive ways of defining and framing risk. Through both intentional and unintentional actions, risk can be shifted between organizations, agencies and social groups in ways that redistribute, rather than reduce, risk and that transfer and exacerbate vulnerabilities (Eriksen et al, 2021). This is not simply the type of risk shifting conducted by insurers but, for example, the legal shifting of risk from power companies on to the people of Texas evident during the 2021 winter storm.

Box 1. The 2021 winter storms

In the February 2021 winter storms in the United States of America, the power grid in Texas partly failed. This left some 5 million people without power for days during unusually cold weather where the temperature reached a low of -17°C. Water supplies ceased and gas pipelines froze, affecting consumers and firefighting efforts, as well as retail and many other key services. Some retail power companies also went bankrupt as a result. The deregulated nature of the grid, its lack of connection to national grids and severe load shedding meant that wholesale electricity prices increased by a factor of nearly 200, with individual consumers facing electricity bills of up to $1,000 a day (Henson, 2021).

Consideration of the word "risk" in disaster research and policy encourages enquiry into broader risk contexts (that is, risk without disaster) and the underlying causes of disaster events. There is now greater emphasis on process rather than on the event or outcome (Davis, 2019). The formulation of risk as the function of hazard, exposure and vulnerability (plus capacity) is a foundational framework in the study of disaster across research areas and certain sectors such as insurance, as it encourages interdisciplinary analysis of the natural (i.e., hazards, environment) and the social (i.e., vulnerability, exposure, capacity) dimensions of risk (Wisner, 2004). It is acknowledged, however, that this and some other dominant risk framings are derived from Western scholarship and, in a global sense, there is no single view of what risk is and how it is formulated. There is, therefore, a need for more diverse ways of understanding risk, such as that provided by indigenous knowledge or by practitioners (Gaillard et al., 2019).

For example, a participant in the indigenous engagement process, Professor Jonathan Procter, stated

> *"It's obvious that it's a completely different understanding of risk for indigenous communities. In my experience, in New Zealand and the Pacific and South-East Asia as well, in some ways there is no real understanding, or no concept of risk in traditional cultures. Pre-European or pre-colonization, it's been very much a case of adapt and survive … and through those adaptation strategies, knowledge is developed and solutions have developed, … responding or … living with many of the challenges they faced in the environment."*

There are also sectors where risk seems to be overlooked; for example, risk can appear to be treated as an externality in current development models, and groups that focus on the perceived benefits, for example through economic analysis, argue that the risks are small compared with the benefits. Many countries, sectors and companies have their own standards and protocols for formally assessing risk, often drawing on ISO-31000, the international risk management standard, which frames risk in terms of 'the effect of uncertainty on objectives'. There are many disciplinary and sectoral approaches to risk. These range from the mathematical modelling of the engineering, insurance and the finance sectors, the approaches used by the society and technology research community, and cultural and social theorists.

Much broader approaches are also emerging, such as the increasing use of the SDGs to frame risk for public and private organizations and the strong social justice framing of risk brought to bear by environmental and climate justice, human rights and labour advocates. The discounting of risk in traditional economic analysis is being challenged by new approaches through, for example, the work of the Task Force on Climate-related Financial Disclosures and proposals to help ensure inclusive wealth-building for both human and natural capital (Dasgupta, 2021).

This indicative set of ways of seeing risk has now been joined by a range of concepts which highlight risk as an immense challenge for both humanity and the planet: systemic and complex risks, and risk as existential.[1] These concerns have led to new fields of study, with a focus on global catastrophic and existential risks, namely events that could bring humanity, or parts of humanity, to collapse (e.g., Centre for the Study of Existential Risk (CSER)).

A systems approach to risk is one way of understanding the increasingly connected and complex socio-ecological systems within which risks manifest (see the *Global Assessment Report on Disaster Risk Reduction* (UNDRR, 2019)). However, conventional framings of risk still often overlook temporal and spatial collisions of different hazards, or the collision of extreme events with slow onset events or protracted crises (Keys et al., 2019; Phillips et al., 2020). Anthropogenic changes and globalization processes further exacerbate risks. Concepts such as compound risk, systemic risk, cascading risk, NATECH (natural hazards triggering technological disasters) risk, and Anthropocene risk have emerged as alternative framings that attempt to capture the dynamic nature of risks in "modern" systems.

The notions of systemic risk and Anthropocene risk centre on interdependency as a driver of risks. The former focuses on networked elements while the latter calls attention to the context of linkages. Adopted from the financial management field, systemic risk refers to risks rooted in interconnected components of a whole. Events affecting one component may result in the collapse of the whole system. Systemic risks tend to be large scale, non-linear, interconnected and stochastic in nature (Lucas et al., 2018; Renn, 2021). The interconnections often become clear only as a crisis unfolds.

The concept of Anthropocene risk (Keys et al., 2019) seeks to explain emerging global risks and how they arise, with humanity seen as the main driver of change on the planet. Understanding Anthropocene risk requires holistic and systemic approaches (Folke et al. 2021). These more complex risks, or ways of thinking about risk, are emerging as sub-disciplines with their own substantial research efforts. They reflect a merging of global environmental change, escalating inequalities, digitalization, economic and social issues and crises, which are both creating new forms of larger risks and uncertainties and entrenching and exacerbating many day-to-day risks.

The focus on global risk stems from growing concern about the prospects for humanity and the life-supporting capabilities of the planet. The threats are seen as complex and intensifying, but are subject to a range of interpretations. Regardless of the exact severity of the threat, the implications are high levels of disruption to the lives and livelihoods of much of humanity, disruption or partial cessation of the global flows of goods and services, including the ecosystem services underpinning humanity, and the undermining of future or reversing of past achievements of the SDGs, climate adaptation and disaster risk reduction.

This global focus should not obscure the reality that, for many people, it is the everyday risks, vulnerabilities and crises they face that are of major concern. Global risk is nevertheless important to the extent that it is connected to, and a driver of, these local issues and can also provide opportunities for risk reduction with consequent improvement for human well-being.

Consistent with the ways that risk is framed and viewed, and with the imperative of collaboration across disciples, sectors and forms of knowledge, this agenda uses multiple framings in developing its priorities. Risk is highly pluralistic in nature, with multiple interconnections, dimensions and scales and complex impacts. It is therefore important to find ways to work with these diverse, elements and with uncertainty and surprise across planetary and

4

The disaster risk field: evolution and emerging issues

4.1 Science and research

Modern disaster studies in the fields of geography, sociology, anthropology and engineering, among others, have developed since the 1950s, although the area of study has long antecedents. The journal *Disasters* began publication in 1977, for instance. Since that time, disaster knowledge and practices have evolved from an emergency management framing to a broader perspective encapsulated by DRR (Davis, 2019). There has been a shift in priority and focus from responding to disaster events (i.e., an ex post approach) to proactively managing and reducing risks (i.e., an *ex ante* focus). As mentioned earlier, risk is often seen as a function of hazards, exposure and vulnerability (and capacity), and this way of framing risk has become foundational to how disaster processes are conceptualized.

Crucial to progress in understanding and managing disaster risk is "disaster science", which spans both natural and social sciences and cuts across various disciplines including environmental, earth, economics, geography, engineering, sustainability, ecology, sociology, political science, law, education, health, anthropology and other sciences and sources of knowledge, as well as their specific branches. Figure 4.1 and figure 4.2 show, respectively, the almost exponential growth in scientific publications over the last 50 years and the disciplinary origins of bodies of disaster-related literature (for more details, see the Literature Review Working Paper, included in Appendix 3).

Figure 4.1 Literature search results per year (1970–2020)

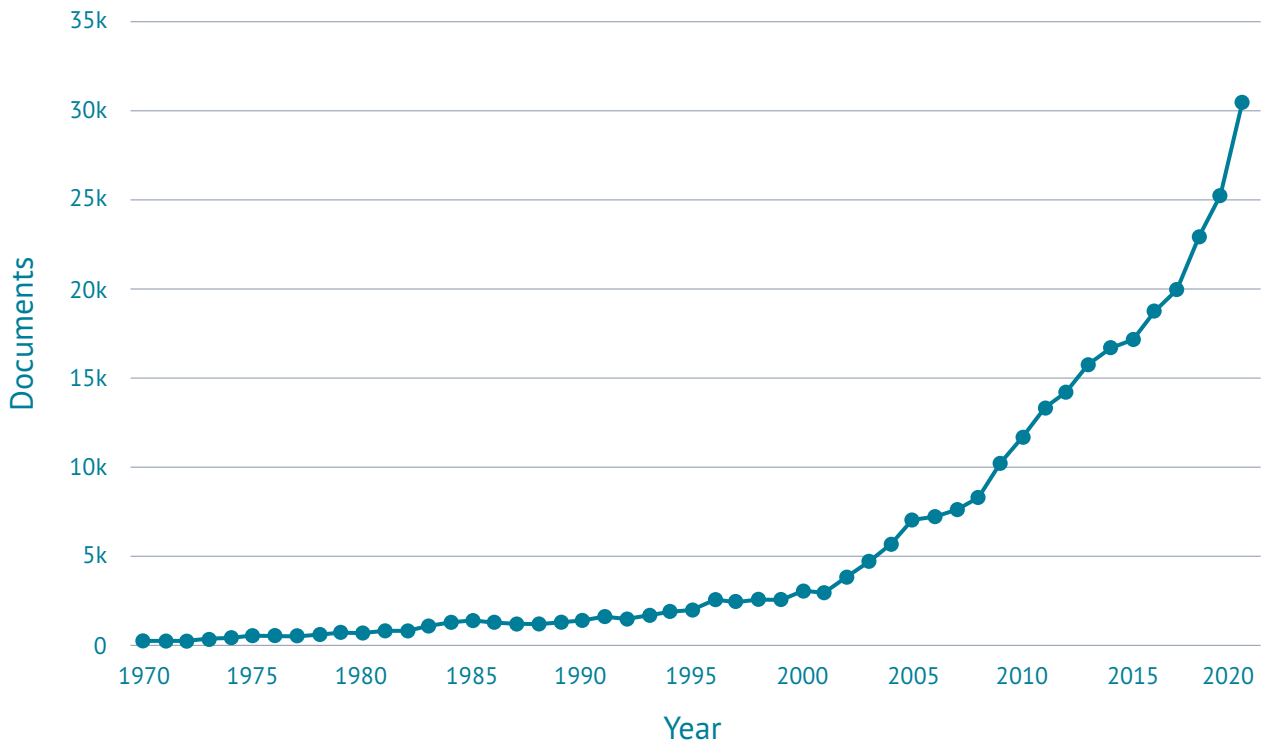
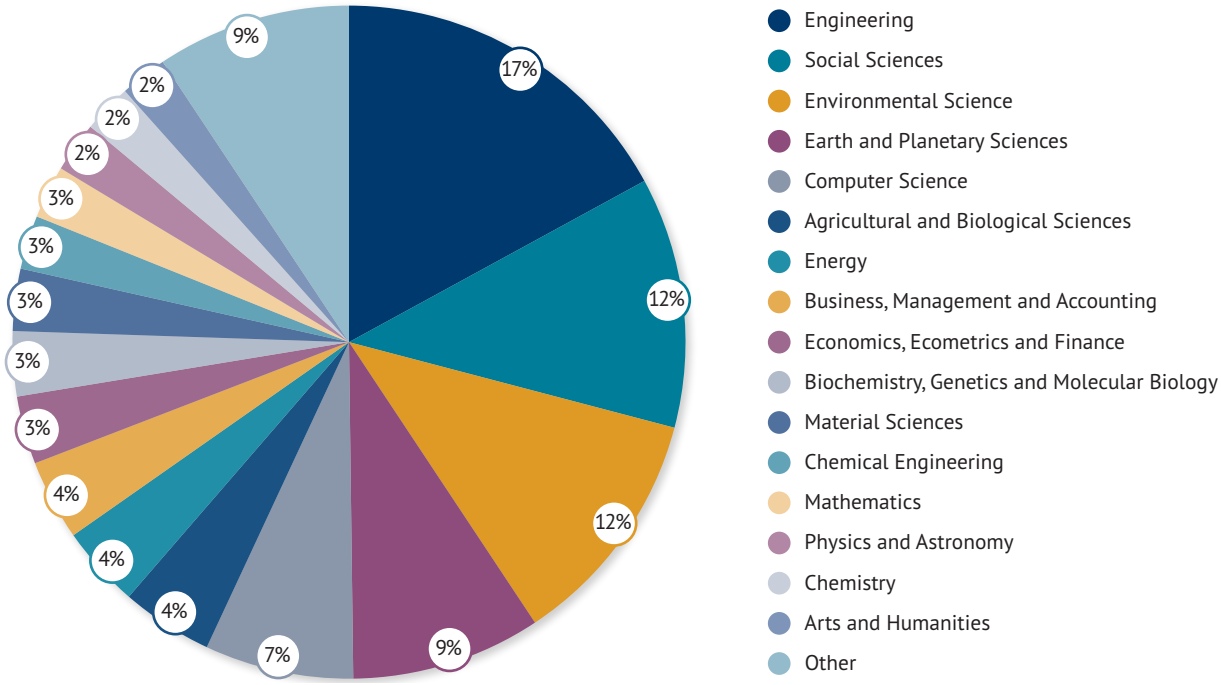


Figure 4.2 Literature search results (1970-2020) by scientific discipline (excluding medicine)



Disaster risk science is constantly evolving, its concepts and framings refined, contested, and redefined across diverse and interrelated disciplines. In the context of increased global connectedness, the evolution of risk understanding from "natural" to "systemic" is apparent. It is central to how risk, hazard, vulnerability, resilience, and adaptation, among others, are framed and their cascading, compound and interacting impacts. The increasing role of the social dimensions of risk and vulnerability has brought to the foreground local, traditional and indigenous knowledge and methodologies as critical components of disaster risk science.

Innovations in scientific methods and technologies, in particular geospatial and mobile technologies, and big data (see Priority 5 in section 5), have enabled new ways of knowing, understanding, measuring, and assessing (Shaw, 2020). The confluence of these trends and progress calls for meaningful and inclusive collaboration across scales, geographies and disciplines and for progressive governance approaches to risk reduction and management. As science and research in these areas continue to grow at an almost exponential rate, multiple agendas, coalitions and processes have emerged at all levels, from global to local, around which disaster scientists and researchers are able to coalesce in the hope of informing disaster risk policy and practice.

There are various gaps and priorities reflected in scientific literature, inputs to this agenda and beyond. First, a growing disconnect between knowledge and action is apparent. The desired shift from ex post to ex ante approaches to risk management, for example, has not been mirrored equally between disaster risk science development and policy and practice. One reason may be the lag between conceptual and theoretical advances and grounded knowledge and empirical data; another the lack of effective science to policy communication; and another the frequent tension between science and partisan politics. Secondly, a holistic understanding of risk is lacking. While there is a plethora of quantitative and qualitative approaches to understand the manifestation and perception of and responses to risk, there is as yet no integration of approaches that also account for diverse, place-based ways of knowing and understanding. There is a rise in multi- and transdisciplinary approaches, but more needs to be done to integrate different forms of knowledge, beyond science and experts, to include traditional and indigenous knowledge and approaches. Thirdly, across scales and between regions and nations, knowledge production suffers from significant imbalance and disparities. A future research agenda needs to be conscious of power relations informing and being informed by disaster risk science and to make space for locally produced knowledge to help drive understanding and progress.

4.2 Policy and implementation

Global action on disaster reduction commenced at least as early as the 1970s, while formal policy developments can be traced to the 1990s United Nations International Decade for Natural Disaster Reduction; the Yokohama Strategy and Plan of Action for a Safer World, adopted at the first World Conference on Natural Disaster Reduction in 1994; the Hyogo Framework for Action 2005–2015, adopted at the second World Conference on Disaster Reduction in 2005; and to the Sendai Framework for Disaster Risk Reduction 2015–2030, adopted at the third World Conference on Disaster Risk Reduction in 2015. The names of these events and processes alone suggest a gradual shift from thinking of disasters as natural events to a broad acceptance that the risk- and development-related decisions and actions that humans take determine the risk and the disaster impact.

This shift in thinking has led to the necessity to reduce risk to grow as a priority on global policy fronts, not least in relation to climate change and sustainable development, as encapsulated in the 2030 Agenda for Sustainable Development, the SDGs, the Paris Agreement on climate change, the post-2020 global biodiversity framework, the New Urban Agenda, the Addis Ababa Action Agenda and the Agenda for Humanity. These agreements and others highlight that DRR is now recognized as a mainstream development issue, providing the global policy foundations for more integrated and holistic risk governance and for more equitable outcomes in improving the condition of people and the planet. Despite this, the Sendai Framework mentions but does not specifically prioritize the need to identify and tackle the underlying causes and drivers of risk, suggesting that science and policy advances are still required. Greater synergies and coherence across the areas covered by these agreements could address this and transform the ways in which risk is conceptualized and governed.

Figure 4.3 The evolution of thinking on DRR showing the emphasis and global agreements for DRR through time with rationale and thinking

The policy environment is now quite different because the agreements on DRR (the Sendai Framework) climate change (the Paris Agreement) and the SDGs did not exist before 2015; earlier integration across the domains that these agreements cover was at best ad hoc and often unofficial. Change can also be seen in the rise of transdisciplinary approaches, but they need to extend much further to include forms of knowledge beyond that of science and scientists. Traditional science alone is not sufficient to deal with the contemporary complex risk environment, with its emerging risks and growing uncertainties. There are many institutions working on these risks, both alone and in coalition with others, including civil society networks, research and independent policy organizations, United Nations agencies, think tanks and others with major influence such as the International Federation of Red Cross and Red Crescent Societies (IFRC), World Economic Forum (WEF), World Bank and European Commission. The affiliations of members of the agenda's Core Group and Expert Review Group highlight some of the diversity.

The 2020 *Hazard Definition and Classification Review* (ISC & UNDRR, 2020),[2] with its reappraisal and reframing of which hazards should be included within the scope of the Sendai Framework highlights one aspect of this evolution in thinking. Drawing on the Sendai Framework, the review applies a new definition of hazard from phenomena to also include human activities and processes. It sets out a strong case for an "all-hazards approach to achieve risk reduction as a basis for sustainable development". This is intertwined with the systemic complex nature of the contemporary hazards landscape, epitomizing the evolution of the whole DRR field, as noted in that review: "the increasingly interconnected, cascading and complex nature of natural and human-induced hazards, including their potential impact on health, social, economic, financial, political and other systems, are all interlinked in the discussions on sustainable development and climate change adaptation." An important next step for this hazards review is to expand its sources of definitions to include local knowledge and experience.

RESEARCH PRIORITIES

5

Research priorities

This section sets out the research priorities. These priorities have been developed through the consultations undertaken as part of the agenda development (see Section 2 and Appendix 1), through the gaps and needs identified by the analysis of published material (Section 4 and Appendix 3) and through examination of key documents including the *Global Assessment Report on Disaster Risk Reduction 2019* and the 2020 *Hazard Terminology and Classification Review* (ISC and UNDRR, 2020). The field is very dynamic, with new issues and priorities certain to emerge over the short and medium term. Much of the context for this work is now set by COVID-19, as the enormous research and policy efforts dedicated to most aspects of the pandemic, and the insights generated, will likely have a profound impact on disaster risk thinking and management (Mizutori, 2020). The virus has had a direct effect on hazard and disaster management through the requirements to reduce infection risk and the reduced ability to move people and expertise. Vulnerabilities and limits in governance and capacity have been dramatically highlighted, as have the stark differences in risk perception.

The priorities set out below should be read with other major research priority-setting exercises in mind, such as the Horizon Europe Strategic Plan (2021–2024); the 2020 United Nations *Research Roadmap for the COVID-19 Recovery*;[3] the Earth Commission; *Our future in the Anthropocene biosphere*, the report prepared for the 2021 Nobel Prize Summit (Folke et al., 2021); and the 2019 *Global Assessment Report on Biodiversity and Ecosystem Services* by the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services. The emerging fields of Planetary Health (The Lancet, 2015) and One Health (Mackenzie and Jeggo, 2019), with their emphasis on the indivisibility of human and Earth system well-being, are directly relevant.

The consultations identified that much research and progress has been achieved in DRR, but that much knowledge remains unused. Silos and significant disconnections remain within and between disciplines and other sources of knowledge, as well as between knowledge producers and potential knowledge users. This lack of integration and absence of a transdisciplinary focus has reduced the capacity and impact of disaster risk science to support action to address macro societal challenges, including alleviating poverty, reducing vulnerability and exposure to all forms of disaster risk and improving risk governance.

Implementation of many aspects of these higher-level priorities will require major change and, in some cases, transformation, whether of social and behavioural, institutional, political, policy-based or other aspects of the current risk science and research paradigm. Consequently, a key overarching question is: how can transformation be achieved? It is acknowledged that transformation will rely on identifying diverse and multiple pathways for transition and collectively defining a vision of where risk science should be in a decade from now, how this will be achieved and how success will be measured. There will likely, and legitimately, be more than one single vision.

In seeking to encourage change towards an integrated approach to risk reduction and human well-being across sectors, funders and sources of knowledge, including transdisciplinary risk science, the research priorities are set out so as to include macro-level issues; some more specific technical concerns; and priorities at the regional level, including the complexities of regional differences, development and implementation challenges. The priorities are set out under broad themes, with additional details given in appendix 4. Examples where rapid impact or early results are likely to be achieved are highlighted. These are provided as indicative examples where, due to a combination of existing knowledge, capacity and institutional support, rapid results are likely.

The priorities are:

1. Understand risk creation and perpetuation: systemic, cascading and complex risks
2. Address inequalities, injustices, marginalization and vulnerabilities
3. Enable transformative governance and action to reduce risk
4. Understand the implications of new thinking on hazards
5. Harness technologies, innovations, data and knowledge for risk reduction
6. Support regional and national science and knowledge innovation for policy and action
7. Support just and equitable transitions, adaptation and risk reduction
8. Measurement to help drive progress
9. Foster multi-stakeholder collaboration for solutions to risk challenges.

By way of overview, figure 5.1 illustrates how the themes or research priorities discussed in the following subsections fit together as a whole. Importantly, the themes should not be viewed as mutually exclusive as there is considerable overlap between the priorities. Each area of research fits with the overall objective of augmenting the global risk science and knowledge ecosystem to better address the challenges of facing intensifying global, regional and local risk. Most priorities can apply in a range of contexts, from global to local, and from rural to highly urbanized areas.

Figure 5.1 Overview of the nine priority areas of research

5.1 Priority 1: Understand risk creation and perpetuation in the contemporary risk landscape: systemic, cascading and complex risks.

The rapidly evolving global risk landscape demands better understanding of complex and systemic risks and of the interdependencies that increasingly confront humanity and the planet. Knowledge of these underpins risk reduction action and avoidance of biophysical and social "tipping points" which could lead to sudden increases in vulnerability through loss of livelihood, food and water security, among other issues, for large sections of humanity. It is evident that many aspects of these global risk issues are grounded within the SDGs, which need to take account of disaster risk as well as the transition risks that accompany change to a more sustainable world (see Priority 7, below). This is because climate change, disasters and unaddressed inequalities and issues of justice can rapidly undermine development gains and lead to the perpetuation and deepening of vulnerability, poverty and other drivers of risk (see Priority 2, below). Currently, the impacts from disasters and day-to-day problems often worsen vulnerabilities at the same time as some hazards are worsening; dealing with such impacts is a key element in achieving progress towards the SDGs and risk reduction. Further research on these issues is needed to understand disaster risk construction and the intersections between global forces and local impacts. There are important questions about how these risks, tipping points and interdependencies are defined, assessed and monitored and what the implications for planetary health and governance might be. The focus is very much on the problem, but there may also be opportunities for positive change offered by capitalizing on tipping points, for example (Lenton, 2020).

The fields of systemic and existential risks are new and emerging (at least as fields of study and policy) and are reshaping DRR. The concepts, definitions, approaches to assessment and appropriate governance are all contested; there is no agreement on terminology or scale of application, among other issues. As a result, there is no common approach or agreement on how to approach these issues. Despite these significant uncertainties, this is a key area, and identifying appropriate ways forward is properly part of the identified research gaps and needs,[4] including institutional arrangements and funding. Tackling these issues opens up new areas of potential collaboration with the Earth system science communities and others. Insights will not come from science alone: other sources including indigenous and local knowledge and the experience of practitioners should be part of future work.

Recommendation 6 of the *Hazard Definition and Classification Review* supports this priority:

> "There is an urgent need to investigate further the direct and indirect linkages and effects of natural, biological, technological and other human-induced hazards to identify better and understand cascading and complex hazards and risks in a systematic way. The shift towards a broader view and a more context-dependent definition of hazards requires a systematic approach to risk that considers hazard, vulnerability, exposure and capacity together and better understands their complex interactions."

Potential early result: how can comprehensive risk assessments, which include global threats, systemic impacts and inequalities and vulnerabilities, be undertaken with local communities? What framing and form do such risk assessments need to take?

5.2 Priority 2: Address inequalities, injustices, marginalization and vulnerabilities.

Key to reducing risk is understanding further the dynamic nature of exposure, vulnerability, resilience and capacities, with particular focus on how risk science and knowledge can strengthen risk governance, policy and practice to best ensure justice and equity, and support the inclusion of the most disadvantaged and marginalized people and communities. Included in this conceptualization of marginalization is the marginalization of sources of knowledge outside mainstream science, including indigenous knowledge. Consultations emphasized the need to better understand how diverse concepts of resilience and vulnerability guide practice. Models of resilience should not overlook power asymmetries, nor that there are multiple states of "desired" or "aspired for" resilience across different global contexts.

A fundamental aspirational aim of DRR and the SDGs is that "no-one is left behind" (IFRC, 2019), yet many marginalized and less visible people are excluded from risk and vulnerability reduction programmes. The question is how to ensure that the most marginalized are included. One issue is the reliable identification of such groups. Rights-based approaches, as used in country reports by the United Nations Special Rapporteur on extreme poverty and human rights offer one way forward.

At a strategic level, one of the most challenging questions for global risk and the SDGs concerns how to address global inequalities in their many forms. Such inequalities drive increased marginalization and deepening vulnerabilities among many communities in both developed and developing countries. Confronting inequities, injustices and rising vulnerabilities through new social and economic systems at different scales from local to global should be examined (Folke et al. (2021) provide a current analysis). Consideration should be given to alternative approaches to addressing global inequalities as proposed, for example, by Piketty (2014; 2020), who argues for wealth taxes, public and universal provision of quality education and health care, a redefinition of property to limit ownership and a global transactions tax. Recent reports by the Organisation for Economic Co-operation and Development (OECD) examine potential alternative economic systems, both pre and post COVID (OECD 2019; 2020).

Potential early result: how can risk science best support the development and adoption of tools that enable practitioners to consider risk and its distributional impacts when defining development strategies?

5.3 Priority 3: Enable transformative governance and action to reduce risk.

What formal and informal governance arrangements across the public, private and non-profit sectors, and civil society can promote synergies between the major global agreements to reduce risk and vulnerabilities?

Transformative governance is about driving fundamental change towards sustainability and the SDGs. Ideally it involves multiple stakeholders across multiple scales, from both formal and informal institutions (International Institute for Applied Systems Analysis (IIASA), 2021). This overlaps with but is different from adaptation or DRR, where "strengthening governance is identified as essential to reduce disaster risk" (Amaratunga et al., 2020), but is, by itself, unlikely to lead to major change.

The rationale for enhancing governance coherence across the substantive areas covered by major global agreements is that it offers opportunities to develop systemic risk governance capable of working across, and undertaking the necessary transformation to implement, the major global mandates for DRR, climate and human well-being. It should also help to avoid duplication across complementary research areas and missed opportunities for transdisciplinary social reach and capacity development. It should also enable stronger science and knowledge-based contributions to the SDGs, Paris Agreement, New Urban Agenda and other international agreements, and enhanced use of existing networks (e.g., the Association of Southeast Asian Nations; the Inter-American Institute for Global Change Research[5]) within risk knowledge and science. In this context, coherence refers to consistency, synergies and mutual reinforcement.

The use of the SDGs in order to frame risk is under examination in the world of corporate, private and public organizations (Principles for Responsible Investment (PRI), 2017), and could be part of the governance needed for transformations to sustainability. It offers an opportunity to achieve both conventional risk reduction as well as the normative goals of the SDGs. However, much more may be required; indeed, in many cases, regeneration is required beyond sustainability per se. Understanding the role of different actors, including mediating actors – those who act as go-betweens, negotiators, or gatekeepers – is key to providing better support for systemic risk governance. A systemic approach to governance will require a move away from institutional and scientific divides that create arbitrary separations between, for instance, DRR and development.

Full or even partial achievement of any one of the Sendai Framework, Paris Agreement or the SDGs requires similar achievement of the others because of the interdependencies across the agreements and many overlapping objectives and synergies. One overarching question is how can governance best contribute to this essential integration and critical

reflection for risk reduction? Coherence across the global research network and the identification and examination of what is already known would allow a focus on producing the required knowledge. Another approach would be to emphasize informal networking and governance structures, possibly aided by technology.

Potential early result: what is known across science and other sources of knowledge, including commerce, about integrative governance and action for DRR, climate change adaptation and the SDGs?

5.4 Priority 4: Understand the implications of new thinking on hazards.

The ISC/UNDRR 2020 *Hazard Definition and Classification Review* redefines hazards in the context of DRR, drawing on the Sendai Framework. The redefinition of hazards goes far beyond the traditional hazards of floods, drought, storm fires etc, and extends to most biological, technological and some societal hazards and, by extension, most of the hazards that climate adaptation and the SDGs are explicitly intended to avoid or redress. The Sendai Framework does not include hazards related to violence and conflict, although some countries are reporting on these hazards under the Sendai Framework Monitor. Armed conflict and social instability and tension are recognized hazards in humanitarian law and are incorporated into the *Hazard Definition and Classification Review*, which specifically lists international armed conflict, non-international armed conflict, civil unrest, explosive remnants of war, environmental degradation from conflict and violence.

That report was "guided by the definition of 'hazard' adopted by the United Nations General Assembly (UNGA) in February 2017", namely "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". It should be noted that some substances were also included. Importantly, "hazard information when combined with exposure, vulnerability and capacity is fundamental to all aspects of disaster risk management, from multi-hazard risk assessments for prevention and mitigation to warnings and alerts, to disaster response and recovery, long-term planning and public awareness."

Sources of knowledge and experience outside science, such as local and indigenous knowledge, would be especially valuable in many contexts under this priority. Further work on vocabularies covering the SDGs and on incorporating local hazard terminology would be valuable in future versions of the *Hazards Definition and Classification Review*.

Other key issues concerning hazards include:

- **Understanding new forms, or newly common forms, of extreme hazard behaviour:** This relates to the need to understand emerging complex and systemic hazards and risks. These are emerging from the traditional DRR suite of hazards, for example, extreme flame behaviour in wildfires, extreme heat and atmospheric changes interacting with other potential hazards; as well as occupational hazards; chemical hazards, such as persistent organic pollutants and endocrine disruptors; and economic and livelihood hazards arising from globalization and, now, from a biological hazard in the form of COVID-19, which is arguably, at least in part, itself a product of globalization.
- **Understanding interactions across hazards, vulnerabilities, etc.** These have sometimes been seen as fairly linear and almost obvious, such as extreme heat and wildfires, but can be very complex and potentially systemic as with COVID-19, which highlights the coupled interactions between human/social environment and nature – and this is with respect only to the virus, rather than the systemic impacts of the disease. Armed conflict constitutes a particular challenge both as hazard and as a potentially risk-magnifying context for other hazards such as flooding or crop diseases. Our knowledge of these potentially very complex interactions is limited; a first step would be to determine how research could best address this.
- **Targeted impact-based forecasts and warnings.** Improved early warnings, particularly in terms of their reliability and lead time, are desirable for all hazards and essential for many where warning systems are poorly developed. An early warning system needs to be an end-to-end system consisting of essential elements that work together to create a single, cohesive and robust process. Accurate forecasts of hazard behaviour, based on understanding

of the hazard, are a key component of warning messages. Assessment of exposure to the hazard and the vulnerabilities of what is exposed provides information on likely impacts in the areas needing the forecast and warning (World Meteorological Organization (WMO), 2021). This is also a major focus of the HIWeather impact-based warning project led by WMO. There are many related activities, for example, the Climate Risk and Early Warning Systems initiative.[6]

Potential early result: how to develop and action impact-based warnings drawing on multiple disciplines, agencies as well as the private sector and civil society?

5.5 Priority 5: Harness technologies, innovations, data and knowledge for risk reduction

Rapid technological advances in the areas of artificial intelligence, digitalization and analytical capacity and the very widespread adoption of mobile devices and social media are driving major changes in our lives and have the potential to contribute to all aspects of risk reduction and disaster management. However, new risks and systemic vulnerabilities can also be created from the misuse or unintended consequences of the technology. This duality in a hyperconnected world is exemplified by the COVID-19 pandemic, not only in how the disease spread, but in how knowledge and expertise were shared and related ethical issues were dealt with. Understanding and managing contemporary connectivity is therefore a key part of resilience building. There are a number of specific ongoing technical developments that are of relevance to DRR, as set out below. Further to the consultation process (see appendix 1), this section draws on the expertise of ETH Zurich in its work on emerging technologies, DRR and the public (Center for Security Studies, ETH Zurich, 2020). It also draws on the expertise of the international CODATA group (the Committee on Data of the ISC), the IRDR Disaster Loss Data (DATA) Working Group and the Aerospace Information Research Institute at the Chinese Academy of Sciences. In 2019, CODATA produced a white paper, *Next Generation Disaster Data Infrastructure*, which attempts to integrate data needs across DRR, climate change and the SDGs.

Modelling and technical capacity are currently very limited with respect to global and lower-level systemic, cascading and compound risks, even though some models, such as global climate models and models of the global economy, are well resourced and widely used despite many uncertainties. Improved understanding of the emerging global risk landscape is at least partly dependent on better modelling of the underlying processes. Global information and communications technologies can help with both risk reduction and the achievement of the SDGs, but they are also leading to other forms of inequality.

Some potential areas for further exploration and study include:

- **Digitalization** is the defining technological trend of our era. The increased connectivity where everything is being connected to everything else, our dependency, or over-reliance, on such systems including for logistics and retail, and their huge energy requirements, increases social and economic vulnerabilities and creates new systemic risks. Uneven access to the beneficial aspects of digitalization and its widespread use for surveillance, fraud and misinformation are exacerbating inequalities and creating new forms of vulnerability. These new types of risk affect all stages of DRR and sustainability and are not well understood (Renn et al, 2021).
- **Artificial intelligence capabilities** are developing rapidly and promise greatly enhanced analytical capability, particularly for complex and novel risks. At present, however, artificial intelligence lacks judgment, and brings a range of ethical and legal issues that need addressing.
- **Big data and social media** offer the ability to widen the social reach of risk information and to guide engagement at national and international levels to influence social change, as well as humanitarianism. They can greatly expand the scope of inclusion through crowd-sourced data and analysis (Akter and Wamba, 2019). Through its capacity to visualize, analyse and predict disasters, big data is changing humanitarian operations and crisis management. This in turn raises the issue of how the data, and the outputs created from the data, are managed and made accessible[7]. A key issue is the promotion of accessibility and exchange of data from multiple data repositories.

- **The interaction between people and the new technologies** is an overarching issue: there needs to be better understanding of the factors that impede or support technologies in achieving inclusive risk reduction – rather than, for example, risk shifting or risk creation – and how technologies can be better used to support the SDGs and risk reduction through enhanced public engagement and organization (United Nations Development Programme (UNDP), 2021).

Potential early result: what are the factors that impede or support the technologies in achieving their promise of inclusive risk reduction, rather than creating or shifting risk?

5.6 Priority 6: Support regional and national science and knowledge for policy and action

Each region of the world is likely to have its own unique concerns and priorities for both disaster risk reduction and global risks. While the global risk priorities set out previously apply in most places, the details, priorities and day-to-day lives of the people will vary. Regions have distinct mixes of hazards, exposures and vulnerabilities, with their associated interdependencies, capacities and governance structures and trends. They also have their own approaches to, and priorities within, the SDGs and other global agreements, as well as trends in demographics, economies, livelihoods, Governments and human security. It is likely that regional priorities will also be important at the global level and should form part of a reappraisal of existing priorities. In this context, capacities refer to the availability of resources, expertise, trained people and governance and inclusion. Importantly, however, simply having capacity does not necessarily mean it is used effectively.

Members of the IRDR community (the IRDR Scientific Committee, International Centres of Excellence National Committees and International Programme Office and its own networks) were asked to identify any regional concerns that were different from the global priorities already identified. Review commentary from the Core Group and Expert Review Group provided additional material. This a first step in identifying current key regional issues and priorities – some examples of which are given below – but further regional engagement is required. Intergovernmental Panel on Climate Change (IPCC) regional assessment reports may also provide relevant information. These points were derived largely from pre-COVID experiences; nevertheless, the fundamental issues are likely to have changed only slightly as a result of the pandemic. Examples of regional priorities include:

- *South and Central America:* Focus on vulnerabilities and capacity building for resilience; inclusion, especially of indigenous and diverse local voices; and transboundary issues.
- *North America:* Institutional difficulties arising from complexity of vertical and horizonal governance responsibilities.
- *Asia:* Issues of coherence and governance and highly uneven resourcing and capacities across the region, and major transboundary issues.
- *Pacific and other small island developing States:* Climate change and justice issues, including mitigation, retreat, climate evacuation/diaspora. The context is one of small countries with very high levels of exposure to multiple hazards, rapid urbanization, low levels of development and services of all kinds, including those related to the SDGs, and limited capacities.
- *Africa:* Governance, especially of transboundary risks; conflicts; large population movements and limited resourcing; and the need for enhanced efforts on capacity development for local science and technology.
- *Europe:* All hazards of significance, with climate and industrial hazards dominating; a key challenge is the development of models of integrated risk management incorporating multi-risk events and their impacts on justice and equity. The context is that of the European Union (EU) providing an overarching body assisting with risk reduction and management.

Potential early result: how can regional research leadership bring substantive global research together with national and local contexts to drive inclusive risk reduction to reduce vulnerability and risk in future development?

5.7 Priority 7: Support just and equitable transitions, adaptation and risk reduction

The concept of a "just transition" comes from concern that those employed in some sectors will lose their livelihoods as economies are decarbonized in response to the climate crisis (International Risk Governance Center (IRGC), 2021). The process for achieving this vision should be a fair one that should not cost people or communities their health, environment, jobs, or economic assets; in other words, it must not increase their vulnerabilities, and should work instead to promote the SDGs (this links to Priority 2 on inequalities). Major transitioning has happened many times in history, with examples including automation of mining, agriculture and much manufacturing (World Resources Institute (WRI), n.d.). Unfortunately, many affected in this way historically have not found new comparable employment. As the International Labour Organization (2015) notes: "A just transition for all towards an environmentally sustainable economy … needs to be well managed and contribute to the goals of decent work for all, social inclusion and the eradication of poverty."

Under this priority, the scope of "transition" is broadened to include justice around disaster risk reduction and climate adaptation; the question is how to ensure a just and equitable transition to a sustainable, less risky world. Issues surrounding just transitions are seen as particularly urgent in the global South.

Across the world, there are large, informal workforces with low livelihood security, no formal safety nets and usually no representation in public discussions about major change. There may also be significant gender dimensions with livelihood insecurity. Negative impacts vary with the circumstances and the type of measure: from low, for warning systems, through to very high, with permanent relocations, and loss of livelihoods and identity. There are also strategies with significant environmental impacts, such as major engineering works. Disaster risk reduction can result in major relocations, loss of livelihoods and sense of community, unaffordable housing as a result of new requirements and, in the case of humanitarian aid, unintentional undermining of local economies and livelihoods. Risk assessments and management plans should explicitly include the additional risks associated with risk reduction and management strategies.

However, the immediate and severe disruption to most national and subnational economies and sectors as a result of COVID-19 provides some good examples of rapid adjustment by government, the private sector and civil society. These generally relate to temporary actions, whereas permanent shifts will be required to bring economies into line with climate change adaptation and decarbonization, to implement the SDGs and to reduce disaster risk. Unfortunately, there are also cases where, under cover of the COVID-19 pandemic, authoritarian power has been extended and basic rights as set out in the SDGs have been ignored or reduced.

There is also some recent positive action; for example, the EU has established a Just Transition Mechanism,[8] which will fund projects that are consistent with EU climate and energy goals. This is for the regions most affected by the transition to carbon neutrality and is part of the EU crisis response mechanism. Social transfers can be important, but secure livelihoods and implementation of the other SDGs are needed for a sustainable future. This requires more than high-level action by Governments. City and local organizations are often key to managing transitions but can lack the necessary power and capacity. The impediments to local organizations and innovative solutions and the restrictions on civil society and local community actions need to be removed. Although there is some government and corporate action, especially in the global North, peer networks and learning may be more useful at the local and municipal level.

Potential early result: how can relocations driven by transition, adaptation or disaster risk reduction, be undertaken to minimize the impacts on livelihoods and identity?

5.8 Priority 8: Measurement to help drive progress

What do we need to measure and how can measurement be designed to incentivize improved risk knowledge and progress with risk reduction and development?

Recommendation 5 of the *Hazard Definition and Classification Review* is to: "operationalise parameters for exposure, vulnerability and capacity, building on the UNGA definitions". The report goes on to note that: "Much work has been done in defining and standardising parameters for exposure in the context of natural or geophysical hazards, and in defining indicators of vulnerability for disaster risk reduction, but no consensus exists in the definition or application of exposure or vulnerability for use in risk assessment across the list of hazards within the broad scope of this report."

Measurement is generally undertaken for an assessment purpose, such as evaluation or assessing progress towards an objective. This can take place at multiple scales, from the individual components of risk and the dynamic processes driving vulnerability, through to global systems and processes. It includes evaluation of risk reduction options and their impacts, across systems and sectors, with the aim of determining incremental and transformative strategies to achieve inclusive risk reduction and development imperatives (Mochizuki and Naqvi, 2019). Measurement, monitoring and evaluation are only useful if they feed into a process for review and improvement.

There are many indicators for the constituents of risk, but they are subject to a number of shortcomings. One challenge is to develop indictors or measurement tools that incentivize positive change. There is some existing work in this area: for example, the development of indicators to drive risk literacy and awareness, and associated behavioural transformations, at a societal scale (e.g., CSER). Measurement in particular requires understanding systemic and complex risks, as well as existential risks, where uncertainty is often very large and important aspects of the risk may be unknown. This also applies to some better-known issues; for example, there is a necessity to better understand what is meant by vulnerability, and how and what is to be effectively measured particularly in the context of systemic risk and tipping points of intersecting vulnerabilities (Chisty et al., 2021).

Ultimately, the broader need is to assess progress in meeting risk reduction and development objectives such as those set out in the Sendai Framework, the SDGs and other global frameworks. These each have their own targets and indicators of progress; however, as with those for the elements of risk, these indicators are often contested.

Potential early result: how can we best measure progress towards reducing risk in development through addressing Priority 2 and drawing on current knowledge and experience?

5.9 Priority 9: Foster a transdisciplinary approach and multi-stakeholder collaboration for solutions to risk challenges

Researchers and knowledge holders across DRR and risk science frequently observe that there is much in the way of research results and other knowledge that appears useful, actionable and pertinent to the policy or practice issue in question, yet remains unused (Albris et al., 2020; ISC, 2020). This was well articulated in the European Environment Agency's (EEA) reports on late lessons from early warnings (EEA, 2002; 2013). This particular issue was raised directly or indirectly in most of the consultations during the development of this agenda, and affects policy and practice across public, private and non-profit sectors.

Risk assessments constitute an important area of knowledge. Many such assessments are undertaken at every level of governance, but often have no impact on decisions or policy. There are a number of reasons for this, which need to be identified, and there is also a need is to ensure that appropriate risk assessments influence decisions at every level. Participants in the indigenous consultations identified risk assessments as an area that would especially benefit from the inclusion of diverse local and cultural perspectives.

There are, however, many exceptions where research does inform policy and practice. These include, for example, the information and communications sector; finance, including transactions; reinsurers; aviation safety; and, in the public domain, much of the health sector, surveillance and some service provision. In addition is the extensive knowledge held by practitioners in the form of experience and practice, forms of traditional knowledge held by indigenous and local communities and cultural knowledge held by societies. Unlike modern science, which is codified and published, these forms of knowledge are often documented in other ways and are less recognized globally. This agenda emphasizes the need to legitimize and mainstream all sources of knowledge. Efforts should be made to identify areas for collaboration and collective debate and investigation across all forms of knowledge and sectors.

Why do research, discussions and policy debates often seem not to influence change? First, knowledge needs to be in a form that leads to action that is useful for the risk reduction task. Then the challenge is to develop effective ways of ensuring it informs policy and practice, in an environment of competing personal, institutional and political priorities, which can be hostile to science and technical expertise. The transdisciplinary nature of risk science and knowledge, bridging sectors and stakeholders, may be central to finding solutions. This challenge is being taken up by the new approaches of "One Health", and "Planetary Health", among other initiatives. They are characterized as collaborative, multisectoral, transdisciplinary approaches working locally, nationally and globally, aiming to improve the health of people, animals and the supporting environment. They recognize that human well-being is tightly connected with the health of the planet.

For this to happen, science and scientists need to change. The transdisciplinary nature of risk needs to be reflected in the way that knowledge is developed, organized, communicated and applied. We need a substantial shift towards a more inclusive, integrated approach if major risk problems are to be addressed. The responsibility for this shift should be shared among all knowledge holders and users. A starting point could be provided by the many existing international, national and subnational networks of interest; however, most are weak at integrating research and practice. The many active networks of the global South could be better connected with the North for mutual support. Mapping these networks could be a useful exercise to improve collaboration and sharing of expertise and resources (see Section 6). An important limitation of most likely all such networks, and the associated mapping, is that they represent formal arrangements and rarely include local communities, the private sector or representatives of the often more creative and innovative arts and humanities sectors. The scope for more informal networks and arrangements, which could be more effective, is large.

Potential early result: what are the most effective ways of developing and supporting networks of practice and knowledge to enable exchange and development of ideas and interaction with policy and practitioners?

IMPLEMENTATION

6

Pathways to impact and transformative change

> *"We need to make the 'last mile our first mile'. We need to be more responsive to the heterogeneity of the community and its needs. We need more grassroot and social innovation in the field of DRR, and there needs to be a platform for social innovation in DRR, leading to entrepreneurship development."*
>
> – Professor Rajib Shaw, School of Media and Governance in Keio University

Framing research priorities is one thing, but pursuing them and achieving the desired impact and transformative change alluded to throughout this agenda is a separate challenge altogether. Ultimately, the vision of this agenda is for risk science to support risk reduction in terms of both what is known (i.e., understanding risk) and how various forms of knowledge are put into action (i.e., disaster risk action and governance, and governing how science is done in the future in relation to equity within decision-making and practice, implementation and funding). There is a great deal to unpack within this, and this section outlines some pathways and considerations in implementing the risk science agenda and its priorities. These pathways are broad and general in nature and each needs to be evaluated, discussed and applied appropriately according to the context and local realities in order to create a diversity of pathways and approaches to implementation.

As Bauer and Kirchner (2020) note, the apparent effectiveness and attractiveness of change does not by itself ensure implementation, which depends on a wide range of contextual, incidental and deliberate impediments and enablers. Similar sentiments have been echoed in various COVID-19 pandemic implementation efforts globally. The pandemic, which came on the back of many armed conflicts, the disastrous 2019–2020 bushfires in Australia and the west of the United States, among other major disasters, has threatened progress towards the SDGs but has also provided a lens through which to view the deep corners of complex risk and vulnerability. Given that the global risk landscape is increasingly diverse and complex, it is essential to inspire increasingly diverse and inclusive approaches to coping with risk and vulnerability in equitable ways.

Box 2. The knowledge-to-action challenge

To achieve transformative change at a societal scale, the transfer of knowledge from all sources to policy and practice (i.e., action) needs to be much more effective. This co-design should be in the form of a dialogue between all those involved. While significant bodies of knowledge and evidence on risk and DRR exist within an array of scientific discipline, stakeholder networks and local groups, they can be fragmented, inaccessible and not applicable to risk reduction decision-making, practice and implementation. This may be due to a number of factors, such as ineffective knowledge production, limited multi-stakeholder collaboration, especially of those bearing the risks, uncertainties and a perceived lack of legitimacy of scientific evidence, limited capacity, cognitive and political biases, power imbalances and social inequalities. This challenge partly explains the limited progress towards international goals and national priorities, as well as the need for science and action to work more closely together to address growing challenges and meet transformative goals.

It is intended that this agenda will actively address this knowledge-to-action challenge through its implementation across the range of ways in which DRR knowledge is framed, contested and carried by and across various geographies, cultures, sectors and spatial and temporal scales. Approaches to implementation must be conscious of these implications and challenges and must make space for different forms of knowledge in governance and decision-making to drive

progress. More than ever before, the confluence of rapidly increasing risk trends and slow risk reduction progress demands more meaningful and inclusive collaboration across scales, geographies, disciplines and sectors and more progressive governance approaches.

The ways in which risk reduction challenges are framed, and more importantly by whom, remain key challenges in creating a just and fair framework and agenda. Such vital considerations encourage the collective questioning of the ethics and openness of the current science system. The knowledge-to-action focus highlights the need to examine the legitimacy of current scientific knowledge creation and validation processes, and the equity and inclusion of wider groups within this multi-scaled, expanding and iterative dialogue.

In this vein, engagement with the global caucus of indigenous scientists, organized as part of the development process for the agenda, emphasized that achieving impact and transformative change will require more open approaches to judging the scope and validity of what counts as "relevant knowledge", where such scope and validity in general continues to be framed by global science (Menzies and Butler, 2019). The democratization of science also requires a more pluralist and equitable framework (Jacobson and Stephens, 2009). There is a strong aspiration for respectful integration, where the legitimacy of, and trust in, science will be enhanced with more active attention to respecting differently situated knowledge cultures and by recognising that legitimate knowledge is derived and tested in diverse ways and not solely contingent on what are considered scientific methods (Whyte, 2018; Sarkki et al., 2014; Lahsen, 2005).

As already mentioned, feedback was sought from the private sector on this framework to clarify the current role and value of private sector engagement with risk science and research. In general, private sector actors tend to view risk very broadly or holistically (i.e., beyond disasters), and have developed risk assessment and management tools in line with this broad view of risk. This has clear alignment with the new hazard framings and terminologies outlined in this framework and elsewhere, such as in the *Hazard Definition and Classification Review*.

Engagement with private sector actors strongly emphasized that, while efforts are ongoing, it is paramount that risk science be extended beyond existing disciplinary networks and echo chambers to enhance innovation and ensure that useable knowledge reaches the right places. For example, the perspective of Chloe Demrovsky, President and CEO of the Disaster Recovery Institute International and board member of the global ARISE network) captured during the consultations, outlines the opportunities to align with private sector actors globally, but also the impediments of doing so, such as talking about risk using "different languages" and issues of knowledge accessibility. The following quote highlights different sectoral understandings and nomenclatures on risk currently limit the transfer and use of valuable knowledge between sectors and communities.

> *"As we know, it can be complicated to get the private sectors, these communities speaking the same language [referring to private sector and risk science communities] … even though they are addressing the same risks and sometimes have overlapping work, they often use different words to describe it [risk], they talk to different people, they have different conferences and it [cross pollination] can be tricky to co-ordinate. … It is also difficult to approach the private sector as a single stakeholder. The private sector is a really diverse set of the actors with a diverse set of needs and preferences."*
>
> – Chloe Demrovsky from IRDR 2021 conference

Similarly, the following quotes from consultation with indigenous scholars highlight the pressing need to continue interrogating knowledge equity, democratization of science and the place of science and other ways of knowing within risk reduction politics and decision-making.

> *"There seems to be some kind of structural mechanism that's missing to be able to bring knowledges together. A lot of the programmes and research and things that are pushed out from funding directives … are so prescriptive [and] don't allow any advice or knowledge from indigenous peoples to be incorporated. As a result … a lot of maladaptive actions have been going on."*
>
> – Professor Cheryl Anderson, Director, LeA International Consultants

> *"[For] people who are living in the home village, there is a clear understanding that there are global risks [but they] are completely beyond our control. We feel if our sovereignty and authority and jurisdiction was actually implemented and recognized, we would be able to take better control [at the local level] rather than being external [to the science-based response]."*
>
> – Professor Kyle Powys Whyte, University of Michigan

> *"Right now, with the COVID pandemic … we [the Gitxaaala Nation, Northwestern British Colombia] have active living stories of several European and colonially induced disease waves that hit our communities … [this] affects responses - both official responses, with resistance to officials that are coming in trying to tell us what to do, as well as community sense of perceptions of fear and worry and anxiety … It's really important to understand the living history and the response are based in these active remnants and memories of the past … there's a long history and understanding of incorporating response to disasters that affect the way in which our people organize and respond today."*
>
> – Professor Hagwil Hayetsk (Charles Menzies), Department of Anthropology, University of British Colombia

> *"[The issue] is the disproportionate burden of exposure to risks and hazards … that indigenous populations, particularly in more remote and isolated communities are now having to bear … embedded within colonial management and legislative policies. It's the Government that both controls and governs and regulates what kind of hazards might be allowable within a community … there is a great deal of distrust."*
>
> – Professor Michelle Driedger, Department of Community Health Sciences, University of Manitoba

> *"All things in the environment have a soul; they are alive beings. So, from our perspective, the science needs to be open to further understanding, because science is about transforming the phenomenon into data [and] to a process of objective understanding … losing the subjectivity. So, from our perspective, science can achieve some results, but it's not enough to overcome [the] many risks we face … the communities are at the centre of [this] knowledge."*
>
> – Professor Danilo Silva Guimarães, University of São Paulo

These insights speak to areas of increasing focus in social research and raise a variety of issues that need examination if risk science is to emerge as truly equitable in the future, including:

- questions of equity in areas of policy and law, and whose voices are at the forefront of decision-making and why;
- opening science to scrutiny to enhance equity between science disciplines and other ways of knowing and doing, as differently derived and equally valuable "knowledge spaces" (Turnbull, 1997: p. 553; expanded by Mazzocchi, 2006);
- understanding drivers of risk, as well as needs and priorities for future risk research from diverse perspectives, in a way that embeds concepts of risk in local places and shifts managing risk as single events and disasters towards emphasis on preparedness and societal resilience.

There is much discussion within the framework of the need for work across sectors by all relevant actors. A first step to progressing the knowledge-to-action objective, which is central to implementation, is to map areas of convergence, divergence and how perspectives and emphasis differ across groups to identify areas of collaboration, debate and investigation. The Planetary Health and One Health approaches offer examples of the intersectoral and transdisciplinary way of working that is required.

In line with the vision of this agenda, science working across disciplines, sectors, groups and with communities and other sources of knowledge, is actively encouraged as fundamental to achieving transformative change. Open science prepared to work in a transdisciplinary manner is integral to this vision, with fields of science and practice, communities, informal networks and collectives working together. It is important to underscore, however, that generic approaches do not fit all contexts. This is the key reason why the operationalization of the research priorities outlined in the agenda is challenging; solutions must be designed for the unique circumstances of each location and community by those involved. This section does not seek to be prescriptive, but instead inspire innovation and to give visibility to diverse viewpoints (including indigenous communities, local and informal groups) within future dialogue on risk. In the light

of the agenda's vision of risk science contributing to the transformation to a lower risk, more sustainable world, the following pathways emerged out of agenda development processes.

6.1 Pursue transdisciplinary science and multi-stakeholder knowledge co-production

The transdisciplinary and multi-stakeholder emphasis of this agenda is reflected in engagement undertaken in the process of developing the agenda, which drew on diverse perspectives, from indigenous scholars and communities, through to the private sector and wider stakeholders.[9] From the outset, this agenda has strongly promoted the empowerment of plural knowledge frameworks and acknowledgment of plural solutions. Risk science alone, while of significant value in deepening society's understanding and engagement with risk and vulnerability, will not facilitate the required transitions to enable global society to cope better with escalating risk. Risk science needs to be much more collaborative, transdisciplinary and inclusive and should frame the issues at hand through engagement with other sources of knowledge and with those who fund and implement the evidence generated by science. This will require a multi-scale, persistent and inclusive project of iterative and constructive dialogue between diverse knowledge disciplines/cultures that accounts for diverse, place-based ways of knowing across spatial and temporal scales.

6.2 Enhanced emphasis on multiple contexts in which the roots and expressions of vulnerability to disaster risk may be located.

There is no single view of what a disaster is. It is therefore critical to recognize different ontologies in understanding disasters as well as diverse approaches and epistemologies in researching them. One pathway for DRR science-led research agenda should therefore be more locally led (i.e., ground-up), with national, regional and international agendas for effective risk reduction, as the recent COVID-19 pandemic has shown us in stark consequence at an international scale. As part of this, there needs to be enhanced emphasis on the constructions and measures of vulnerability. As outlined under Priorities 2 and 8, there is a need to better understand vulnerabilities, intersectionalities and risk triggers in diverse contexts; to define effective cross-context and agreed parameters of vulnerability measurement; and to examine how vulnerability impacts on development indices over space and time.

6.3 Enhanced data acquisition, management and implementation

Linked to the issues of the initial framings of risks as outlined above, there is also the need to carefully consider the ethical and justice dimensions of what and whose data counts. Often the need for technical data, while essential, can overwhelm and preclude the necessary debates and critical thinking on the role of more tacit and local data that may also be required to effectively reduce disaster risk. Creating spaces for this form of engagement, by local practitioners and various knowledge holders, including greater participation by social scientists (e.g., anthropologists, philosophers, ethicists and political scientists), can help to expand the discourse on data. Priority guidance and governance guidelines or frameworks, for example, on appropriate mechanisms for engaging with and integrating diverse forms of data and knowledge (traditional and indigenous science, policy ready and actionable knowledge) will be needed.

Depending on the issue at hand, data infrastructure is increasingly seen as central to the implementation and monitoring of policy. Such infrastructure includes the organizational structures, systems and technologies involved in all aspects of data collection, protection and use. It can help to integrate and make accessible ideas and information from diverse sources. This would assist risk science, as it is inherently an integrating domain that draws from, and contributes to, a wide range of disciplines, forms of knowledge and professions. This is also linked to Priority 5 (see section 5).

6.4 Rapid social learning systems that are mindful of various knowledges, values and belief systems

An issue that often arises during implementation processes is the need to adjust and adapt as that implementation proceeds. Rapid learning systems use the best available evidence and local data to inform decisions and commit to learn from their experiences as quickly as possible to enable continuous improvements and to contribute to the global evidence base. For, as Albris et al. (2020) emphasize, "one thing seems certain: we will not need less knowledge going forward".

This is particularly pertinent for this agenda, which needs to remain flexible and adaptable as the needs for and priorities of risk and risk reduction science change. This will require a process for regular monitoring of the global risk landscape, and review and updating of the agenda as needed. Importantly, evolving priorities need to be seen as desirable in a highly uncertain environment and necessary to ensure the currency of the agenda. Changes in these circumstances would in no way be a criticism of the original agenda, rather an acknowledgement that it is designed to evolve. To do this requires better identification of knowledge needs and gaps and building in flexibility to address new priorities as they emerge. There is also therefore a need for a mechanism for the renewal and updating of priorities to ensure that priorities written in 2021 are not static and redundant by 2030 and beyond. As part of the implementation of the agenda, a process for regular review and updating should be agreed.

6.5 Collective and concerted efforts on capacity enhancement to reduce risks

The ever-changing disaster risk landscape is also prompting a change in capacity, training needs, including the long-standing issues of building inclusive risk awareness and risk literacy,[10] and risk management capability. Here once again there is a need for a more expanded recognition of types of knowledge and how this knowledge is framed, understood and gathered. The ability to "make sense of" the types of knowledge gathered and then how to interpret and assess risk and science-policy-practice, and then derive management linkages is also critical.[11] Training in networking and negotiation skills is likely to become more important in terms of working in and developing a transdisciplinary and cross-sectoral approach.[12] Enhanced governance and organizational structures, including those led and informed by community perspectives, are needed to understand and act on reducing risks (i.e., integrative governance and action for DRR).

6.6 Open science

"For me as a scientist, sort of stepping back a little bit … we're really just providers of tools and other ways of doing things that can be led by others in the community … as scientists and practitioners, we provide tools that can help society deal with rapid change at all kinds of scales … [these] tools can only be improved by opening them up and sharing them [beyond the science community]." (Professor Jonathan Procter, from the indigenous consultation)

Open science is about building on epistemological, institutional and strategic gaps as well as building capacity and resources to overcome limits on the transfer of knowledge from science to policy and practice and from practice-policy back to science, thereby enhancing risk awareness and informed decision-making in society (Albris et al., 2020).

The epistemological gap refers to how science and policy, and subdomains within each of these, have different interests and worldviews when it comes to the very conception and framing of knowledge and what it is to be used for. Some of the differences between these two worlds make it inherently difficult to integrate the results of research into disaster risk reduction practices (Albris et al., 2020). Improving the ways in which practitioners, policymakers, scientists and researchers can collaboratively engage and communicate complicated material around the pressing matters inherent to risk reduction and awareness is needed.

The integration of science and policy for risk reduction is not only a matter of dealing with different types of knowledge and the management of uncertainty. It is equally about building governance and institutional capacity. The current weaknesses and impediments to building such capacity in diverse contexts and at different levels can be described

as **institutional gaps.** In order for the risk science community to effectively contribute, its role in relation to the government system in question (municipalities, agencies, ministries and so on) must be clearly identified.[13]

The strategic gap refers to the lack of common vision on how to progress (Albris et al., 2020). A key issue in this regard is communication. There are few opportunities for scientists and related policymakers to debate and discuss issues of relevance and strategic long-term outlooks. On the global stage, standards and international frameworks such as the Sendai Framework have proposed trajectories for the involvement of science in disaster risk reduction policies at the local level; integration and knowledge transfer tend to take place in a sectoral fashion rather than in a cross- or multi-sectoral way. Although international frameworks such as the Sendai Framework place great emphasis on risk reduction and capacity development, including through education and nurturing of disaster expertise, there has not been a similar level of focus on such aims at the national and local levels. For their part, scientists need to understand cultural and institutional nuances in order to create knowledge inputs for sustainable, holistic policies, while policymakers need to develop and embrace more nuanced ideas of innovative knowledge production for disaster risk reduction. However, these two dimensions also sit within complex, localized contexts that also need to be part of the discussion.

6.7 An action plan to implement the agenda

The action plan required to implement the agenda must give attention to a number of enabling contexts and factors, some of which are outlined in the following sections. Across all these factors, the transition to lower risk and greater sustainability needs to be just and equitable, as set out in Priority 7 (see Section 5).

Importantly, this action plan is above all about initiating a process that is iterative, evolves and is shaped by the needs and different contexts of implementation. This document represents the start of this process, hence the action plan that it lays out seeks to encourage and enhance knowledge-to-action outcomes across the wide dimensions of risk science. It is not intended as a prescriptive top-down agenda set in stone for the next 10 years.

6.8 Networks and communities of practice

One research priority of this agenda concerns the need for interdisciplinary knowledge, including experience, and for work with those in policy and practice. This includes a wide range of existing networks, both led by and focused on a range of "networks", namely grassroots communities and business communities as well as the networks led and hosted by scientists within the ISC, UNDRR, IPCC, Future Earth, Global Alliance of Disaster Research Institutes (GADRI, IRDR, Network for Social Studies on Disaster Prevention in Latin America (La Red), Periperi U, the private and non-profit sectors, WEF and various research organizations and think-tanks including Global Future Council on Frontier Risks, CSER, Future of Humanity Institute, and Future of Life Institute.

There are also many faith-based networks that are active in risk reduction and support affected people; the international connections of such groups can be particularly effective in mobilizing support and expertise. There are some connections across these groups, but they need to be strengthened and better linked with networks of practice and policy. Often these are in the form of professional associations for all types of work and interests, local government groupings and higher-level intergovernmental forums. A wide embrace of the "network of networks" thinking is needed to bridge between actors, paradigms and approaches across various scales (See Priority 3, in section 5).

There are incentives for these existing networks and hopefully new networks and communities of practice to take an active role in promoting and implementing the agenda. The main incentive is to reduce the chance that disasters will affect the people and communities, their livelihoods and businesses as well as co-dependencies on environment and ecosystem services. Another would also be to lessen the impact of disasters on food, water and supply chain security. For some groups, another incentive is to develop positions on common interests as a step towards influencing policy and practice. The indigenous caucus, organized as part of the development of this agenda, is one such example, which could continue as a higher-level international or transnational policy discussion on disaster risk.

This agenda aims to contribute to and complement other global science processes and activities; it is focused on 2030, in line with the United Nations 2030 Agenda, and indeed beyond. To realize the aims of the agenda, a range of collaborative implementation approaches need to be developed with stakeholders in industry, finance, health and

other sectors to ensure the relevance and uptake of research progress and possible solutions by society and in the mechanisms of risk governance, policy and decision-making.

A potential action pathway

A major issue facing the interface between science, policy and practice in disaster risk reduction is the lack of platforms and structures that not only enable sharing of knowledge between researchers and government institutions, but the application of knowledge in policies and for them to be informed by effective social practice (Amaratunga et al., 2017). (See also Priority 9 above in Section 5.) Risk web platforms and related online repositories for knowledge sharing, such as the United Nations PreventionWeb,[14] also indicate that the tide is changing with respect to the perceived relevance of scientific knowledge in policy (Antofie et al. 2018). Many national examples of such arrangements also exist. Since 2008, the German Climate Consortium has brought together several scientific institutions to synthetize scientific findings on climate change (Marx et al, 2017). In Switzerland, the recognition of the issue of knowledge transfer and sharing gave rise to the creation of the Mobiliar Lab for Natural Risks in 2013, a private/public partnership hosted at the University of Bern to bridge the interdisciplinary gap between science and disaster risk management practice (Booth et al., 2017). A recent positive initiative comes from the United Kingdom of Great Britain and Northern Ireland's Department for Environment, Food and Rural Affairs, which has launched a catastrophic risk project. The United Kingdom Parliament is also considering legislation on the well-being of future generations.[15] Significant challenges still prevail in allowing scientific research and technological innovations to have a real impact in the domains of governance and policy.

While efforts are being made, including by the European Union,[16] structural mechanisms are lacking for bringing diverse knowledges together to inform and enrich the multi-scale, transdisciplinary and transboundary dialogue on risk and vulnerability.

Examples of specific actions

Scientists working with local communities were asked how a platform could be created for dialogue with diversity in equitable and respectful ways, and whether current global science mechanisms, led by organizations such as the ISC and United Nations, could support that as a strategic objective.

Additionally, commentary from ISC stakeholders, Expert Review Group and Core Group members raised the need to develop and improve forums for knowledge sharing between science, policy and practice communities, public and private sector interests, and government and academic institutions in both developed and developing contexts. They also emphasized the need to enhance the visibility and legitimacy of alternative knowledge holders, such as informal groups and activist and advocacy groups.

6.9 The need for actionable knowledge

A key priority in the implementation of the agenda is refocusing and augmenting the existing risk science ecosystem so that new and pre-existing knowledge is available in forms that are actionable. This means supporting progress towards enhanced integration between science and other sources of knowledge with communities of practice and policy, with the aim of improving accessibility to risk science and its inclusion at the forefront of wider discussions beyond the DRR realm, including societal risk, sustainability and development.

This objective will require working with those expected to implement the agenda at all levels, from international organizations through to communities and households. This means a greater emphasis on co-production of knowledge with all stakeholders and a deepening or relationships between the science community and wider knowledge and implementation communities. This approach will ensure that all have ownership and see the risk-based knowledge developed by diverse processes of co-production as their own, as useable and informative, and hence it should be better implemented.

Overall, the success of this agenda will rely on the relationships built during the process of design and implementation and the buy-in achieved and invested in across disciplines and sectors.

6.10 Funders and donors are critical to the process

Implementation of the priority areas requires funding. Funders and donors must therefore be part of the development process of the agenda research priorities to encourage investment in the identified areas, because they have the capacity to either enhance or reduce DRR vulnerabilities (Eriksen et al., 2021).

Ideally, research funding would contain incentives to promote the aims of the agenda, DRR, climate change adaptation and the SDGs: This would mean funding and research that is more inclusive and more focused on practical impacts. The best way to achieve these objectives is itself a research question. Some major funders of research provide ,at best, limited support for the type of use-inspired science called for in this agenda; others, such as the EU and the calls for proposals on specific issue areas, are increasingly focused on applied research. Other sources of funding exist from various agencies, but their research programmes are relatively small.

6.11 Caveats and challenges to implementation: the precautionary principle

The precautionary principle emphasizes caution and the need for pausing and reviewing before implementing innovations that may prove disastrous. As such, the precautionary principle is of practical relevance as much to risk assessment as to risk management. Precaution also calls for deliberate and comprehensive attention to contending policy or technology pathways (Stirling, 2003; 2007). Far from being in tension with science, the precautionary principle offers a way to be more measured and rational about uncertainty and ambiguity, acknowledging that attempts to assert a single aggregated picture of risk are neither rational nor "science-based".

Endnotes

1. For an up-to-date summary, see Folke et al. (2021); policy-oriented examples such as the *Global Assessment Report on Disaster Risk Reduction* (UNDRR, 2019); the Centre for the Study of Existential Risk; the *Human Development Report 2020* (UNDP, 2020); and *Global Risks Report 2021* (World Economic Forum, 2021).
2. https://council.science/wp-content/uploads/2020/06/UNDRR_Hazard-Report_DIGITAL.pdf.
3. https://www.un.org/en/pdfs/UNCOVID19ResearchRoadmap.pdf
4. See also: https://www.cser.ac.uk/news/special-issue-futures/
5. https://www.iai.int.
6. https://www.crews-initiative.org/en
7. Ethical considerations on data access and recognition of the need for data to be "FAIR" (findable, accessible, interoperable and reusable) are essential. Partnerships for understanding and reporting disaster-related statistics are critical and should include regional economic commissions, the Inter-Agency and Expert Group on Disaster-related Statistics (established by the Statistical Commission in its decision 50/116) and National Statistical Offices, with the area of research being of relevance to the United Nations World Data Forum and other United Nations reporting mechanisms.
8. For more information, see https://ec.europa.eu/commission/presscorner/detail/en/qanda_20_931.
9. Integration between disciplines and sectors is also recognized in Priority 9 (see section 5), which outlines the need to develop formalized channels for dialogue and outcome-focused information-sharing.
10. Examples of innovative tools for this purpose include using comics and scientific literature to promote risk awareness: https://www.weforum.org/agenda/2020/12/3-scenarios-for-how-bioengineering-could-change-our-world-in-10-years/
11. See the CSER submission of written evidence to the House of Lords Select Committee on Risk Assessment and Risk Planning (Avin et al., 2021): https://www.repository.cam.ac.uk/handle/1810/317070.
12. As an example: https://www.cser.ac.uk/news/new-report-pathways-linking-science-and-policy-fie/
13. The connection between science and policy is considered e a priority in implementing the Sendai Framework (Pearson and Pelling 2015); the central issue at stake is how to set up the most effective and useful institutional arrangements that allow the scientific community and scientists employed in government entities to contribute to disaster risk reduction.
14. https://www.preventionweb.net
15. The Wellbeing of Future Generations Bill: https://bills.parliament.uk/bills/2869.
16. https://ec.europa.eu/info/research-and-innovation/strategy/goals-research-and-innovation-policy/open-science_en

7

List of abbreviations and acronyms

CSER	Centre for the Study of Existential Risk
DRR	Disaster Risk Reduction
EEA	European Environment Agency
EU	European Union
IIASA	International Institute for Applied Systems Analysis
IFRC	International Federation of Red Cross and Red Crescent Societies
ILO	International Labour Organization
IPCC	Intergovernmental Panel on Climate Change
IRDR	Integrated Research for Disaster Risk programme
IRGC	International Risk Governance Center
ISC	International Science Council
OECD	Organisation for Economic Co-operation and Development
PRI	Principles for Responsible Investment
SDGs	Sustainable Development Goals
UNDP	United Nations Development Programme
UNDRR	United Nations Office for Disaster Risk Reduction
WEF	World Economic Forum
WMO	World Meteorological Organization
WRI	World Resources Institute

8

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APPENDICES

9

Appendices

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Appendix 1 Agenda Consultation and Development Process

Some steps in development of the Research Agenda (note that there are Terms of Reference for the groups established to help develop the agenda)

Table 1: An iterative process of "co-development"

Milestone	
1	The need for new IRDR Science plan identified (mid 2019).
2	Decision taken to develop an agenda with a much broader reach (end Sept 2019); international collaboration – the doc needs to guide the future form of IRDR and other strategic objectives.
3	Discussion with **IRDR, ISC and UNDRR on what this means and how to proceed.**
4	Establishment of an ad hoc group to guide the process (which becomes the **Core Group** with 19 members consisting of representatives of the ISC, UNDRR, the IRDR SC and IRDR ED and other IRDR and external members), and a sub-group within this as a "**Leadership Group**" to deal with the more day-to-day tasks.
5	Initial Consultations with views and input solicited from the IRDR community (this occurred on a number of occasions through 2020). The **IRDR community** includes the IRDR SC, IRDR IPO, the ICoEs and NCs.
6	Drafting of an outline by Qunli Han of the IRDR IPO.
7	Drafting of a *Guidance document* setting out aims, scope and principles. (Endorsed by CG May 2020). This development of this document was an iterative process with the IRDR SC & IPO and CG.
8	**Survey of IRDR Community & CG for input to the analysis** of the current status of DRR research (June 2020).
9	***Draft report/literature review*** on the current status of DRR published research (July 2020).
10	Drafting and consultations – further discussion on agenda scope and emphasis – meetings with UNDRR, IRDR and ISC.
11	Draft report/literature review circulated to the IRDR and CG and revised in two major iterations.
12	Establishment of the **Expert Review Group (ERG)** (consisting of the IRDR SC, IRDR ICoE's and National Committees, representatives of the STAGs, as well as a wide range of people from diverse backgrounds (science/knowledge, advocacy, funder, private sector) outside the IRDR community) – on going (second half 2020). This group provides input and commentary from a wide range of perspectives.
13	Initial work on an **Indigenous group** to help with agenda development.
14	***Individual discussions with CG members*** to solicit views and inputs (Sept-Oct 2020).
15	*Two meetings with the **45 ERG members in two workshops*** to discuss key questions on scope etc (DATE?).
16	Initial work on a **Private Sector group** to support development of the agenda.
17	*Zero order draft* (Dec 2020).
18	CG meeting and feedback (Dec-Jan 2020/21).
19	Redrafting on the basis of feedback and comments
20	ZOD v2 sent for review to Core Group February 2021
21	ZOD v2 discussed with feedback at IRDR SC meeting 30 March 2021
22	Research Agenda v3 prepared and sent to Leadership Group (Friday 9 April 2021)
23	Research Agenda v3 sent for ERG comment (Monday 12 April 2021)
24	ISC Landing Page goes live with Agenda v3 and survey to stakeholders (12 April 2021)
25	International Indigenous Caucus Consultation Meeting (14 April 2021)
26	Pre-Conference draft for the 2021 IRDR International Conference posted on the conference website: 1 June 2021
27	Conference Draft for the 2021 IRDR International Conference posted on the conference website: 7 June 2021. This is for review by the conference.
28	IRDR Conference (June 9 – 10 2021)

Appendix 2 Members of the Leadership, Core and Expert Review Groups

Table 1: Members of the Agenda Development Leadership Group

Member Name	Member Affiliations	Location
Ben Payne (Lead Scientific Officer)	UNDRR JCDR, Massey University	Wellington, New Zealand
John Handmer (Co-Chair)	RMIT IRDR Science Committee	Canberra, Australia
Coleen Vogel (Co-Chair)	University of the Witwatersrand	Johannesburg, South Africa
Anne-Sophie Stevance	ISC	Paris, France
Jenty Kirsch-Wood	UNDRR	Geneva, Switzerland
Qunli Han	IRDR IPO	Beijing, China
Fang Lian	IRDR IPO	Beijing, China
Michael Boyland	SEI TDDR	Bangkok, Thailand

Table 2: Members of the Agenda Development Core Group

Member Name	Member Affiliations	Location
Ben Payne	UNDRR Massey University	New Zealand
John Handmer	RMIT & IIASA IRDR Science Committee	Australia & Austria
Coleen Vogel	University of the Witwatersrand	South Africa
Anne-Sophie Stevance	ISC	France
Jenty Kirsch-Wood	UNDRR	Switzerland
Qunli Han	IRDR IPO	China
Fang Lian	IRDR IPO	China
Michael Boyland	SEI TDDR	Thailand
Marc Gordon	UNDRR	Switzerland
Irina Zodrow	UNDRR	Switzerland
Wei-sen Li	IRDR Science Committee	China
Jana Sillmann	CICERO IRDR Science Committee	Norway
Alonso Brenes Torres	FLACSO IRDR Science Committee	Costa Rica
Riyanti Djalante	UNU-IAS IRDR Science Committee	Indonesia
Juanle Wang	UNESCO-IKCEST, WDS	China

Member Name	Member Affiliations	Location
Mahefasoa Randrianalijaona	Periperi U IRDR Science Committee	Madagascar
Mark Stafford Smith	CSIRO Land & Water	Australia
Joyce Coffee	ARISE network	USA
Chloe Demrovsky	ARISE and DRI International networks	USA
Huadong Guo	AIR-CAS	China

Table 3: Members of the Agenda Development Expert Review Group

Member Name	Member Affiliations	Location
Anne Bardsley	OECD-DRR group	New Zealand
Jose Machare	WFEO-CDRM	Peru
Jing Peng	WFEO-CEIT	China
Rajib Shaw	STAG	Japan
Xu Tang	INMHEWS, Fudan University	China
JC Gaillard	University of Auckland	New Zealand
Victor Galaz	SRC	Sweden
Markus Reichstein	Risk KAN	Germany
Coleen Vogel	University of the Witwatersrand, Johannesburg	South Africa
Nathanial Matthews	Global Resilience Partnership	England
Franziska Gaupp	IIASA	Germany
Franz Gatzweiler	UHWB	China
Virginia Jiménez Díaz	IRDR SC	Venezuela
Virginia Murray	IRDR SC, PHE	England
Mark Pelling	IRDR ICoE, King's College London	England
Donna Mitzi Lagdameo	RCRC climate centre	Netherlands
Zinta Zommers	IFRC Climate Center	England
Gretchen Kalonji	Dean of Institute of Disaster Management and Reconstruction (IDMR), Sichuan University- Hongkong Polytechnic University	China
Soichiro Yasukawa	Chef of DRR Unit, UNESCO Division of Ecological and Earth Science	France
Giuseppe Arduino	Chef of Section on Section on Ecohydrology, Water Quality and Water Education (EQE), Division of Water Sciences, UNESCO	France
Saini Yang	BNU, APSTAG	China
Chadi Abdallah	Arab STAG	Lebanon
Rita Der Sarkissian	Arab STAG	France/Lebanon
James Terry	Former Chair of ISC Asia Pacific Committee	UAE
Irasema Alcántara Ayala	DRR Committee Member in ISC office in Latin America	Mexico

Member Name	Member Affiliations	Location
Barbara CARBY	DRR Committee Member in ISC office in Latin America	Jamaica
Jose Rubiera	DRR Committee Member in ISC office in Latin America	Cuba
Shuaib Lwasa	IRDR former SC chair	England/Uganda
Djillali Benouar	PeriPeri U and University of Sciences and Technologies Houari Boumediene (USTHB)	Algeria
Clarissa Rios	Research Associate Centre for the Study of Existential Risk, University of Cambridge	England
Marteen van Aalst	Director Climate Centre, IFRC	Netherlands
Roger Pulwarty	NOAA	USA
Scott Williams	UNDP	Switzerland
Peng Cui	IRDR SC	China
Jörn BIRKMANN	IRDR SC	Germany
Bapon (Shm) Fakhruddin	IRDR SC	New Zealand
Haruo Hayashi	IRDR SC	Japan
Nisreen D. AL-Hmoud	IRDR SC	Jordan
Julius Kabubi	UNDRR Regional Office for Africa	Kenya
Animesh Kumar	Deputy Chief, UNDRR Regional Office for Asia and the Pacific	Indonesia
Ortwin Renn	IASS	Germany
Dilanthi Amaratunga	Head, Global Disaster Resilience Centre	England
Alex Altshuler	UNDRR E-STAG	Israel
Richard Thornton	Bushfire and Natural Hazards CRC	Australia
Ranit Chatterjee	IRDR Young Scientist	India
Sufyan Aslam	ISC in Malaysia	Malaysia
David Johnston	Massey University	New Zealand
Lauren Rickards	RMIT	Australia

Appendix 3 Towards a disaster risk reduction research agenda: A literature review

Version: Draft for inclusion as appendix to the Research Agenda. The final version of this literature review is being published as a working paper by IRDR.

Date: 31 May 2021

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Abstract

In light of an evolving global risk landscape that demands new knowledge, action and ways of doing things, a research agenda development process has been initiated under the Integrated Research on Disaster Risk (IRDR) programme. Building on existing science, policy and implementation, the new research agenda aims to provide an inclusive and collaborative platform for innovation and partnerships towards more transformative approaches to conceptualizing, understanding and addressing risk – rooted in disaster risk science. Formulated as part of the research agenda development process, this working paper presents and discusses a state of knowledge around disaster risk science, based on scientific literature review and inputs from the IRDR community, and framed by the emerging priorities of the research agenda. Specifically, this paper i) traces the development and evolution of relevant concepts and frameworks, ii) discusses the application of relevant methods, tools and approaches, and iii) highlights important knowledge gaps.

We highlight how definitions and framings of key risk concepts from diverse and inter-related disciplines are constantly evolving and often contested, and how our understanding of risk has broadly evolved from 'natural' to 'systemic'. Yet, while there is a plethora of quantitative and qualitative approaches to assess risk, a holistic understanding and operationalization of risk is lacking, there is also limited integration of approaches that account for diverse, place-based ontologies and epistemologies across spatial and temporal scales, and knowledge production suffers from significant imbalances and disparities. Further, the relationship between progress in disaster risk science and advances in policy and implementation suggests a growing disconnect between knowledge, decision-making and action. A future research agenda needs to be conscious of power relations informing and informed by disaster risk science, and make space for subalterns studies and locally-produced knowledge to shape governance and drive progress. More than ever before, the confluence of these trends and progress calls for meaningful and inclusive collaboration across scales, geographies, and disciplines, and more progressive governance approaches to risk reduction.

Keywords: *Risk; disaster risk science; disaster risk governance; disaster risk reduction; research agenda*

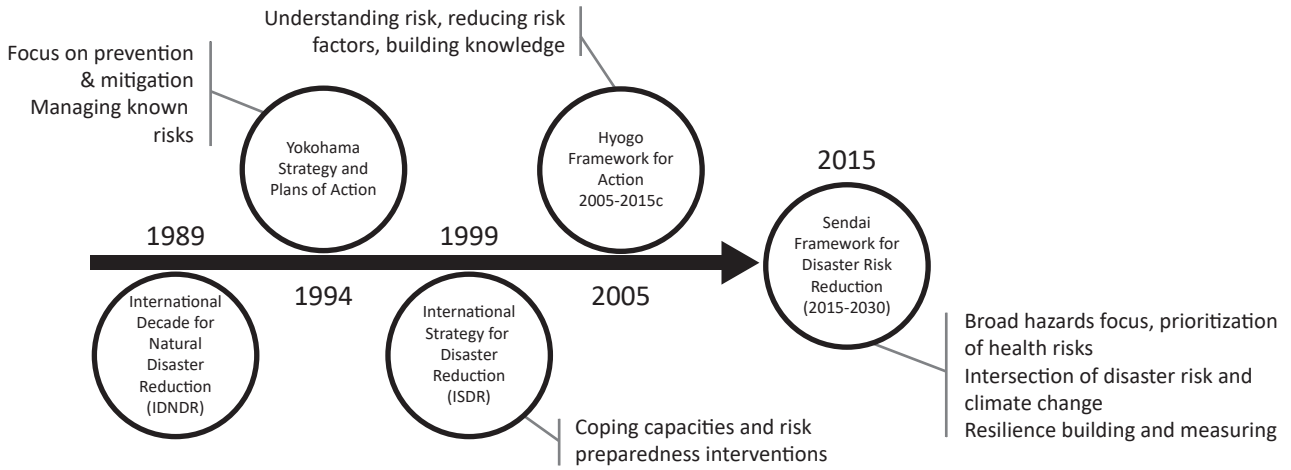
Contents

1 Introduction

Disasters have been studied for centuries, but 'modern' disasters studies have arguably developed over the past half-century or so. The journal *Disasters* began publication in 1977, for instance. During this period, disaster knowledge and practices have evolved from an emergency management framing to a broader perspective encapsulated by 'disaster risk reduction (DRR)' (Davis, 2019). It has seen a shift in priority and focus from responding to disaster events (i.e. an *ex-post* approach) to proactively managing and reducing risks (i.e. an *ex-ante* focus). Risk, it has become widely accepted, is a function of hazards, exposure and vulnerability (Cardona et al., 2012; Wisner, 2004). Social sciences in particular inform our understanding of the vulnerability dimension of risk, with various frameworks emerging in the context of socio-ecological (or human-environment) systems (e.g. Cutter, 2003; Turner et al., 2003). Such framings have become foundational to how risk processes are conceptualised, particularly in Western scholarship.

Global policy developments in disasters (inc. management, reduction) can be traced from the 1990s UN International Decade for Natural Disaster Reduction (IDNDR), to the Yokohama Strategy for a Safer World adopted at the first World Conference on Natural Disasters in 1994, to the Hyogo Framework for Action (2005-2015) adopted at the second World Conference on Disaster Reduction in 2005, and currently to the Sendai Framework for Disaster Risk Reduction (2015-2030), adopted at the third World Conference on Disaster Risk Reduction in 2015. The names of these events and processes alone suggest a gradual shift in thinking of disasters as natural events (or 'acts of God') to broad acceptance that the risk- and development-related decisions and actions that humans take determine the disaster impact. This shift has enabled the imperative to reduce risk to grow in priority on global policy fronts – not least in relation to climate change (Kelman, 2015). These policy transitions are discussed in Aitsi-Selmi et al. (2016) and Tiernan et al. (2019), and summarized in Figure 1 below.

Figure 1. Disaster risk reduction global policy developments



(Aitsi-Selmi et al., 2015; Tiernan et al., 2019)

Crucial to progress in understanding and managing disaster risk is 'disaster science', which spans both natural and social sciences, and cuts across various disciplines, including environmental, earth, economics, geography, engineering, sustainability, ecology, sociology, political science, law, education, health, anthropology and other sciences, as well as their specific branches. As science and research in these areas continue to grow at an almost exponential rate, multiple agendas, coalitions and processes have emerged at all levels, from global to local, for disaster scientists and researchers to coalesce around in the hope of informing DRR policy and practice.

Recognizing the knowledge and impact of existing networks and programmes, the Integrated Research on Disaster Risk (IRDR) programme seeks to establish a new research agenda to guide the development of disaster science in the coming decade. In the face of growing risks, the agenda will facilitate high quality inter- and trans-disciplinary knowledge production, and contribute to the transition to a peaceful, safe, equitable and sustainable world within the context of DRR.

As part of the development process for this new research agenda, this paper serves to provide context, baseline information and a 'state of knowledge' on disaster risk science and related disciplines. Specifically, this paper aims to i) trace the development and evolution of relevant concepts and frameworks, ii) understand the application of relevant methods, tools and approaches, and iii) highlight key gaps in data, information, and knowledge.

This paper is structured by the evolving research priorities of the new research agenda, and provides a literature-based discussion of concepts, methods and knowledge gaps of each priority, before a broader discussion of the implications of the current state of knowledge around these priorities for science, policy and implementation. The following sections present the methodology (section 2), analysis (section 3) and discussion and conclusions (section 4).

2 Methodology

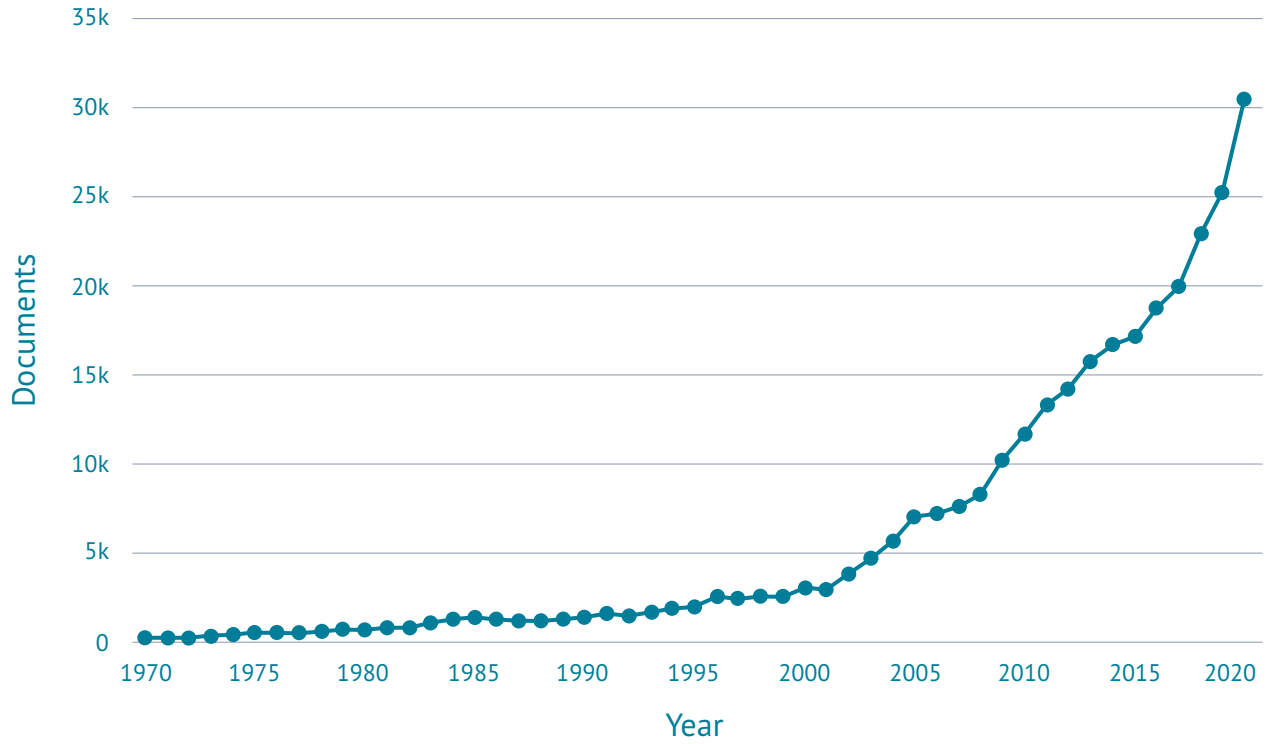
The methodology for this paper is two-fold. Firstly, an online survey was designed and disseminated across IRDR networks (i.e. Science Committee members, ICoEs, NCs) and members of the Research Agenda Core Group to gather recommended literature for review. The survey received 15 responses with a total of approximately 200 (including duplicates) journal papers, edited books and grey literature reports recommended for inclusion in this review.

Secondly, literature was gathered and reviewed from online sources, specifically using the Scopus database accessed through Chulalongkorn University, Thailand. The following 'Title-Abstract-Keyword' search string was used to search for relevant literature in the advanced search function of Scopus:

> *TITLE-ABS-KEY ((disaster* OR emergency OR emergencies OR crisis OR crises OR hazard*) AND (resilien* OR vulnerab* OR adapt* OR mitigat* OR prevent* OR prepar* OR recover* OR reduction OR respond OR response* OR sustainability OR sustainable))*

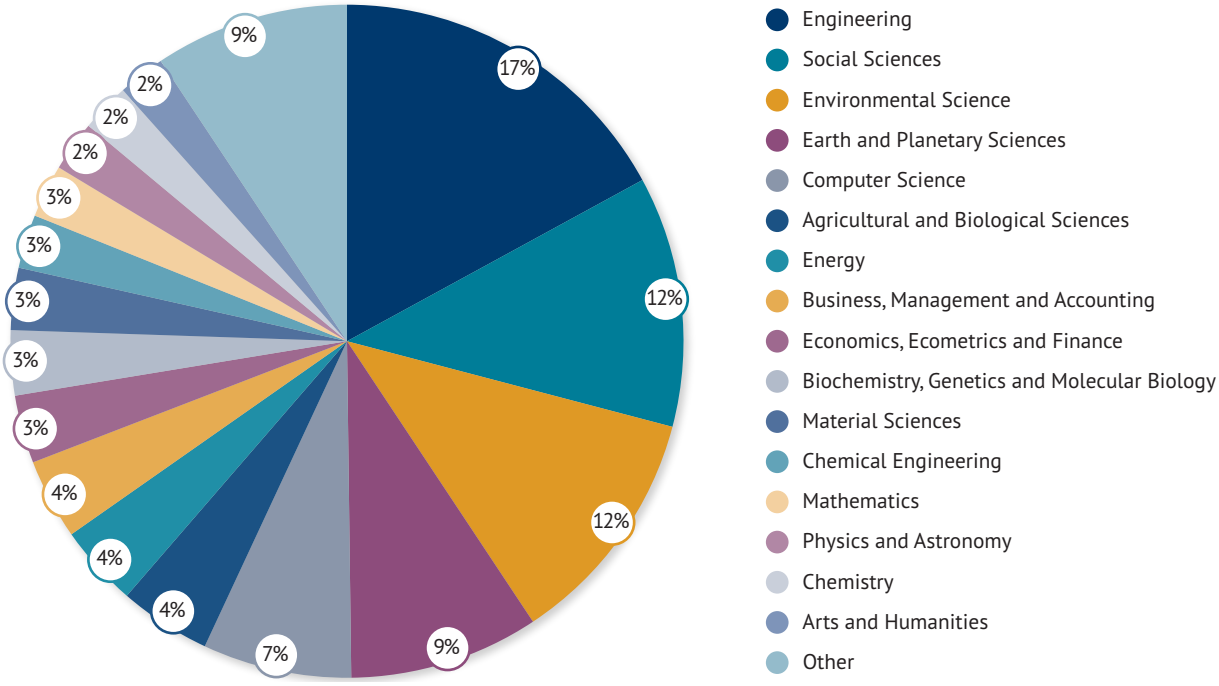
Limiting the results to publications from the past 50 years, i.e. 1970-2020 (inclusive), the search returned over 542,632 results. The search was further narrowed down by excluding publications from the subject area of 'Medicine', which reduced the number of results to 301,333. By way of comparison, an earlier review of disaster science literature found over 27,000 papers published between 2012 and 2016 (Elsevier, 2017). Figure 2 below shows how the number of academic publications has accelerated in recent years. For instance there are 30,579 results for 2020 alone – more than the results for 1970-1997 combined (29,362 results in 28 years).

Figure 2. Literature search results per year (1970-2020).



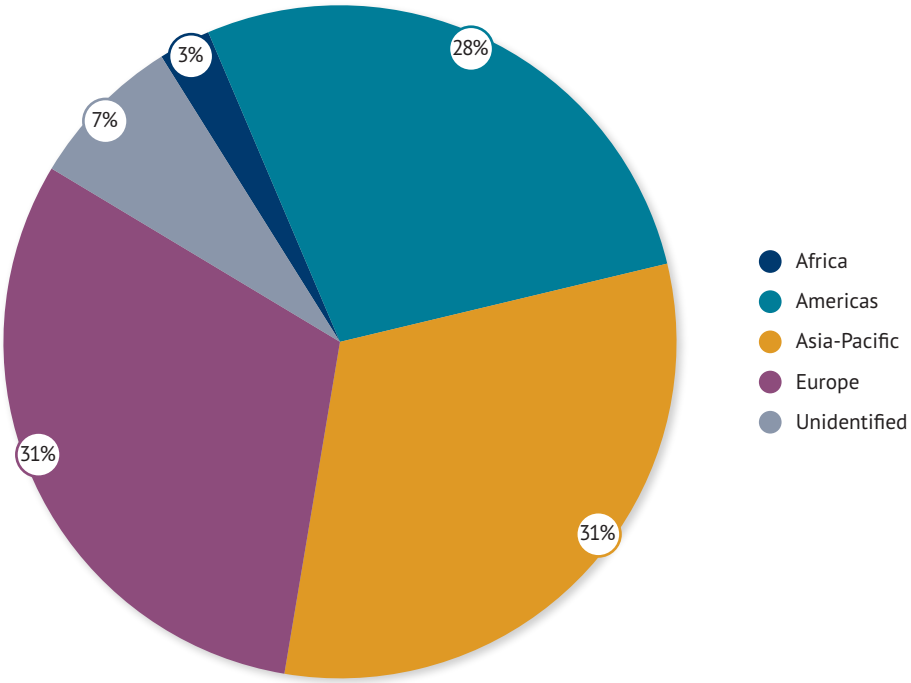
Given the large number of results and non-specificity of the search string, it's also interesting to note the scientific disciplines from which the results are derived. Figure 3 shows the top three to be Engineering (17%), Social Sciences (12%), and Environmental Science (12%).[1]

Figure 3. Literature search results by scientific discipline (1970-2020, excluding 'Medicine').



Results by region, as shown in Figure 4 below, given an indication of where scientific publications are coming from. The headline finding is that there is a relatively even split between Asia-Pacific (31%), Europe (31%) and the Americas (28%), but only 3% of results are from Africa. Three countries dominate the publication of literature – United States (21.8%), China (9.8%) and United Kingdom (6.4%).

Figure 4. Literature search results by region of origin (1970-2020, excluding 'Medicine').



As demonstrated by the large number of results and also the disciplinary origins of some results (e.g. biochemistry, chemistry), it is clear that not all results are relevant for the aims of the paper, and the wider Research Agenda. Therefore, results were further restricted to the period 2010-2020 because IRDR was established in 2010, which produced a total of 206,515 results.

Results were then sorted by 'most cited' in order to prioritize, and the title and abstracts of the results were screened, with irrelevant results ignored, to produce the top 150 relevant results, which were the basis for this review. In addition, Google Scholar and Google searches were used to find literature which systematically or holistically review the literature to provide a synthesis of the state of knowledge on DRR and related themes. Survey results were cross-referenced with Scopus search results and select publications were included for review. Zotero is used as the reference management software.

Papers were reviewed to analyze i) the development and evolution of relevant concepts and frameworks, ii) the development and use of relevant methods, tools and approaches, iii) key gaps in data, information and knowledge, iv) key gaps in science-to-policy engagement, science communications, and research capacity, and v) science for key global policy missions (i.e. Sendai Framework, SDGs and Paris Agreement). The analysis is presented in the paper according to the emerging research priorities *(subject to change and finalization)* of the new Research Agenda, as follows:

1. Understand risk creation and perpetuation: systemic, cascading and complex risks;
2. Address inequalities, injustices and marginalisation;
3. Enable transformative governance and action to reduce risk;
4. Measurement to help drive progress;
5. Understand the implications of new thinking on hazards;
6. Harness technologies, innovations, data and knowledge for risk reduction;
7. Foster multi-stakeholder collaboration for solutions to risk challenges; and
8. Support regional and national science and knowledge for policy and action.

This paper is not without methodological limitiations. The scope is English-language publications only, therefore the paper is based on predominantly Western scholarship. It was also not in the scope of this paper to systematically review all bodies of literature relevant to disaster risk science. Rather, the paper synthesizes and assesses the current state of knowledge around key themes and concepts related to disaster risk science (and DRR more broadly), as well as adaptation, resilience and sustainability. Findings from the review will be used to develop recommendations for future research, policy and implementation.

3 Analysis

In this section we present key insights from the scientific literature for each of the research agenda priority areas by discussing concepts and frameworks, methods and approaches, and knowledge gaps for each.

3.1 Understand risk creation and perpetuation: systemic, cascading and complex risks

The science and knowledge behind understanding (disaster) risk proves increasingly complex. Studies underscore the need to address underlying causes of risks as well as the ways in which risks interact among themselves and with other systems. This calls for new and updated approaches to know, assess, measure and manage risks – trending away from discrete framings of 'disaster' 'climate' or 'environmental' risks, for instance. Further, there is more scrutiny on context-specific socio-economic and political processes within broader systems that create and perpetuate risk accumulation and distribution across geographical and temporal scales. Increased recognition and connectivity between physical/natural and social/political sciences is needed to understand and tackle risks holistically.

3.1.1 Concepts and frameworks

Disaster risk

The consideration of the word 'risk' in disaster studies encourages enquiry into broader risk contexts (i.e. risk without disaster) and underlying causes of disaster events. There is now greater emphasis on 'process' rather than event or

outcome (Davis, 2019). The formulation of risk as the function of hazard, exposure and vulnerability is a foundational framework in disasters studies, as it encourages interdisciplinary analysis of the natural (i.e. hazards, environment) and the social (i.e. vulnerability, exposure, capacity) dimensions of risk (e.g. Cutter, 2003; Turner et al., 2003; Wisner, 2004). It should be acknowledge and discussed, however, that this and many other dominant risk framings are derived from Western scholarship and ontologies, and in a global sense there is no single view of what risk is and how it is formulated. Thus, there is a need for more diverse epistemologies and ontologies in understanding risk (see Gaillard, 2019).

Understanding risk requires taking into account the social, political and cultural construction of risk, or 'root causes' of risk, such as connections with global environmental change, economic development, urbanisation, and demographic shifts (UK Government Office for Science, 2012; UNDRR, 2019). Worldviews and values, informed by socio-cultural contexts, shape behavior and practice in response to hazards, consequently affecting risks (Thomalla et al., 2015). Yet, risk may also be framed as processes where people deal with uncertainty (Eiser et al., 2012), such as in the context of climate change, extremes and variability (Cardona et al., 2012). Responses to risk depend on how people interpret uncertainties. This interpretation is mediated by cognitive heuristics, experience, learning, and trust (Eiser et al., 2012). Thus any disaster response has an inherent or underlying level of risk associated with it.

A systems approach to understanding risk reflects the increasingly connected and complex social-ecological systems within which risks manifest – something which has also been recently recognized outside of academia, such as in Global Assessment Reports on DRR (UNDRR, 2019). However, dominant conventional framings of risk still often overlook temporal and spatial collisions of different hazards, or the collision of extreme events with slow onset events or protracted crises (Keys et al., 2019; Phillips et al., 2020). Anthropogenic changes and globalization processes further compound risks. Concepts such as compound risk, interacting risk, interconnected risk, systemic risk, cascading risk, 'NaTech' risk, and Anthropocene risk have emerged as alternative framings attempting to capture the dynamic nature of risks in 'modern' systems.

Interdependent systems and risks

The notions of systemic risk and Anthropocene risk center on interdependency as a driver of risks. The former focuses on networked elements while the latter calls attention to the context of linkages. Adopted from the financial management field, systemic risk refers to risks rooted in interconnected components of a whole. Poor understanding of their interactions may result in the collapse of the whole system. Systemic risks tend to be global, non-linear, interconnected and stochastic in nature (Lucas et al., 2018; Renn, 2020). There are increasing calls for disaster risk thinking and DRR approaches to better consider and account for other risks (e.g. technological, geopolitical) and promote a system risk approach to disasters (Shaw, 2020; UNDRR, 2019).

Anthropocene risk is a complementary concept that captures the human-environment interactions that inform systemic risks. Anthropocene risk accounts for how anthropogenic changes, cross-scale linkages and global tele-coupling processes interact with traditional risks (Keys et al., 2019). As a conceptual tool, it highlights the need for a new governance architecture that better addresses challenges that are unique to the Anthropocene (ibid).

Risk interaction

Not only are risks intertwined with larger systems, they also interact and collide. There are four types of risk based on the domain in which interactions take place: compound risk (concurrence of natural events in the environmental domain), interacting risk (sequential, triggered events in physical domain), interconnected risk (across physical and social networks) and cascading risk (social and infrastructural vulnerability in the anthropogenic domain) (Pescaroli and Alexander, 2018). Alternatively, when classifying by the nature of the interactions between hazards, four different typologies of compound events are identified, i.e. preconditioned events, multivariate events, temporally compounding events and spatially compounding events (Zscheischler et al., 2020). Such a systematic classification and mapping of risks and their interactions provides the tools for better analytical and modeling approaches that capture the increasing interconnectedness of global systems.

3.1.2 Methods

New and emerging framings that seek to address the complexity of interacting risks require a paradigm shift in analysis and new approaches to assessment and implementation (Shaw, 2020). For example, Zscheischler et al. (2018) call for risk assessment and attribution frameworks that explicitly address compound events using an impact-centric perspective and bottom-up methodology in order to identify underlying drivers and processes. Modeling compound events also requires a comprehensive approach, involving diverse stakeholders' perspectives, the nature and amount of physical variables, spatial and temporal scales as well as the strength of dependence (Leonard et al., 2014).

Traditional approaches, for instance in climate science, largely avoid the discussion of low likelihood events, which are by their very nature deeply uncertain, yet could bear the highest risks and impacts. Event-based storylines, which are physically self-consistent unfolding of past events, or of plausible future events, have been proposed as a way of articulating the risk perspective in such cases, with an emphasis on plausibility rather than probability (Hazeleger et al. 2015; Shepherd et al. 2018). This concept links directly to common practices in DRR using "stress-testing" for disaster preparedness based on events that are conditional on specific (plausible) assumptions.

3.1.3 Knowledge gaps

Further research is still needed to understand, articulate and analyze risk in all of its complexity and uncertainty. New knowledge and understanding of risks means transformation *of* disaster risk science is just as important as transformation in it. In particular, there is a need for more diverse voices from different geographical regions and scales as well as bottom-up (or 'local') knowledge to capture the diverse epistemologies and ontologies related to risk. Participatory, local-led research initiatives as well as indigenous, traditional, bottom-up knowledge and practices will be critical to ensure that science is grounded on lived experiences and tailored to actionable change (Fatorić and Seekamp, 2017; Gaillard, 2019; Kamara et al., 2018). Further effort is needed to unleash the power of local researchers, concepts and methodologies and challenge the hegemonic Western scholarship over disaster science and prevent the loss of local knowledge (Gaillard, 2019; Gaillard and Mercer, 2013). Recognising and contextualizing risks in everyday cultural, political and social experience should be a priority in future research endeavours.

3.2 Address inequalities, injustices and marginalisation

Understanding and addressing underlying causes of risks cannot be separated from interrogating historical and continuing social injustice, inequality and marginalisation. Existing social, economic and political structures make some communities more susceptible to the impacts of hazards than others. Ineffective DRR policy and practice risks reinforce such outcomes, deepening the divide along social, economic and political lines. However, there is great potential for risk reduction and resilience approaches to promote the values of disaster (and climate) justice, which will continue to play a critical role in the sustainability of DRR.

3.2.1 Concepts and frameworks

Disaster justice refers to fairness in policies addressing catastrophic hazards and disasters (Verchick 2012), and "a moral claim on governance" (Douglass and Miller 2018). While it overlaps with environmental, social and climate justice, disaster justice is distinctly shaped by a moral obligation in the context of the Anthropocene, the political nature of disaster governance, everyday inequality that inform vulnerability, and the role of recognition and empowerment in disaster governance (Lukasiewicz, 2020). Disaster justice foregrounds the importance of participatory and inclusive modes of disaster governance, collective agency and just distribution of resources that address underlying causes of vulnerability (Douglass and Miller, 2018).

Meanwhile, other disaster-related concepts and terminologies could also contribute to the reproduction of inequalities and marginalisation. Resilience, for example, has proved a popular concept and framework in disasters and related themes. However, critics argue resilience is now serving more as a 'policy buzzword' than a science or paradigm (Comfort et al., 2001; Reghezza-Zitt et al., 2012). It does not necessarily challenge the status quo and advance our understanding of issues related to risk, vulnerability, poverty and marginalization (Alexander, 2013), while the social-ecological systems approach to resilience has been critiqued for overlooking power asymmetries and assuming the existence of a desired resilient state (Brown, 2014; Gaillard, 2010). Among others, the 'equitable resilience' framing has emerged as a response to such critiques of resilience (Matin et al., 2018).

3.2.2 Methods

Justice research often adopts Amartya Sen's human capabilities approach. In the context of disaster, the framework highlights the link between natural hazards and socio-economic conditions, the importance of democratic values, and community's social, built and natural infrastructures (Verchick, 2012). Another approach frames disaster justice as a governance question, highlighting procedural justice and the roles of different actors in disaster decision making from a longitudinal and multi-scalar perspective (Douglass and Miller, 2018).

Drawing from research on procedural, distributive and interactional justice, Lukasiewicz and Baldwin (2020) propose future research on disaster justice to focus on i) understanding vulnerability and resilience of groups that might not be obviously or visibly vulnerable, ii) tackle rights, responsibilities, accountabilities, values and expectations around disaster management, iii) account for everyday injustices as well as justice issues across the different phases of DRR, and iv) interrogate the connections between procedural, distributive and interactional justice.

In terms of methodological design, there is a need to shift away from over-using the case study approach and instead to adopt evaluative and comparative methodologies in disaster justice research (Lukasiewicz and Baldwin, 2020). In the climate justice literature, quantative and mixed-method analysis remains an open opportunity for future research (Alves and Mariano, 2018).

3.2.3 Knowledge gaps

Social justice and equity remains an understudied area within the literature on disaster and climate change. 'Disaster justice' as a distinctive concept and framing for DRR stakeholders and audiences is only emerging. Research in this area must not be siloed away from critical thinking in other disciplines; multidisciplinary scholarship is needed in order to generate evidence and affect change (Douglass and Miller, 2018). On the climate change adaptation side, a recent review of climate justice literature emphasizes room for improvement in the definition of climate justice and expansion of the research theme (Alves and Mariano, 2018).

The literature also highlights several areas for future research within disaster and climate justice. For example, more work needs to be done on political freedoms and transparency guarantees, as well as on the relationship between gender equality, women's freedoms and adaptation (Alves and Mariano, 2018). There is also a need for research that analyses justice issues at the regional, national and more micro level as well as cross-scale analysis of justice (ibid). Regarding adaptation effectiveness, Owen (2020) finds a big gap in the literature addressing power relations in the distribution of benefits, adaptation process and knowledge production.

3.3 Enable transformative governance and action to reduce risk

Effective and even transformative DRR action calls for governance models that enable unheard voices and collective actions from all actors and stakeholders. The disaster governance literature is an important pillar of DRR scholarship, and suggests several approaches to governance in the context of an increasingly complex riskscape. Yet, translation of knowledge on risk governance to changes in decision-making and action remains a significant challenge across scales.

3.3.1 Concepts and frameworks

Disaster governance is an alternative to the conventional approach to managing disasters through preparedness and response. When governments are unable to effectively and adequately manage risks, disaster governance focuses on collaboration and engagement with stakeholders, and strengthening the voices of local and marginalized actors, across different scales (Gall et al., 2014). Principles of accountability and transparency are central to governance (ibid), and bring in a strong rights-based perspective to disaster- and risk-related decision-making.

New thinking and understanding of risk and its interconnected nature has also prompted new approaches to governance. Adaptive governance, developed from socio-ecological systems thinking, is an approach enabled by multi-stakeholder platforms offers an alternative model for managing complex socio-environmental issues such as disasters, with a focus on collaboration, participation, learning and self-organisation (Djalante, 2012). The transformative potential of adaptive governance in the context of DRR has also been discussed (Munene et al., 2018).

The literature on systemic and compound risks has also explored alternative approaches to analyze and govern risks in the context of increasing interconnectedness. A multidisciplinary approach to globally networked environmental risks, also referred to as global systemic risk or nested vulnerability, identifies five major insights shaping global

governance. They range from the influence of international institutions and international norms and legal mechanisms, to transboundary, cross-sectoral institutions, innovation as strategy and legitimacy issues (Galaz et al., 2017). In addition, scholars have increasingly advocated for integrating disaster governance with climate change adaptation and sustainable development (Gall et al., 2014).

3.3.2 Methods

The literature on disaster governance is abundant when it comes to conceptual studies, yet fewer works focus on operationalizing the transformation in existing risk management structures (Gall et al., 2014). For example, research on the linkages between DRR and climate change adaptation foregrounds the need for improved governance, collaboration, resource sharing, and community engagement, yet few research focuses on operationalization and case studies of context-based implementation (Islam et al., 2020). Applied and or comparative research to generate empirical evidence is needed to understand and facilitate transformative governance to reduce risks.

One potential method to evaluate the effectiveness of (risk) governance is through the use of resilience as an indicator. Yet, resilience itself is a complex concept with different definitions and uses, and noted above and by many authors, and a sound and standardized approach to measuring and documenting resilience is still missing (Gall et al., 2014). Other quantitative outcome measures for governance require specific data and longitudinal research, along with information that captures uncertainty is still missing (Gall et al., 2014).

3.3.3 Knowledge gaps

A knowledge gap exists between the conceptualization of governance at the abstract level and its translation to policy and action. To bridge the gap between theory and practice, Islam et al. (2020) suggest taking the political economy approach improve understanding of decision-making and policy processes with an emphasis on stakeholders and their power dynamics. More qualitative research using participatory, bottom-up and interndisciplinary approach to enrich existing knowledge on adaptation intervention and decision-making processes (Fatorić and Seekamp, 2017; Shaffril et al., 2018) as well as analysis of adaptation finance, implementation action and outcomes (Ford et al., 2011; Klöck and Nunn, 2019; Lwasa, 2015) is also needed. Finally, innovation in risk governance often occurs at the local level while upscaling is challenged by the dominant and powerful structures that maintain a status quo (Galaz et al., 2017). Further research is needed to understand and facilitate cross-scale shifts in governance systems for more transformative DRR.

3.4 Measurement to help drive progress

Disaster science can influence risk governance and drive action in multiple ways. One such channel is building operational understanding of key DRR concepts such as exposure, vulnerability and resilience. These are complex and highly debated concepts with multiple uses and meanings in different strands of literature. Tools to unpack and measure these concepts both qualitatively and quantitatively are needed to influence risk reduction.

3.4.1 Concepts and frameworks

Exposure

Exposure is a major driver of risk subject to influence from existing social institutions and skewed development processes (Cardona et al., 2012). Reflecting the role of climate change in DRR, the notion of 'multiple exposure' refers to susceptibility augmented by exposure to various ongoing challenges, such as climate change, globalization, poverty, epidemic, earthquakes, landslides and more. Climate change is one among many that communities and assets are exposed to, and efforts in response to multiple exposure should be coordinated towards the goal of sustainability (Kelman et al., 2015).

Resilience

While many resilience definitions exist and the word has a long history (see Alexander 2013; Manyena 2006; Zhou et al. 2010), Holling's (1973) definition of resilience as "a measure of the ability of ecological systems to absorb changes of state variables, driving variables, and parameters, and still persist" (Holling 1973, p. 18) is often credited as one of the earliest and most influential for the study of disasters. Coming from the field of ecology, Holling's work first related resilience to a systems theory approach. One particular influence of the origins of the term in ecology has been a dominant emphasis on system stability characterizing resilience in other fields and domains (Alexander, 2013). In a review of disaster resilience themes, (Tiernan et al., 2019) summarize resilience to refer to system attributes: i)

maintaining stability, ii) recovering, and iii) adapting. Resilience is also credited with acting as a bridging concept between DRR and adaptation.

Vulnerability

Multiple definitions of and strands of research on vulnerability, beyond UN glossaries, recognize the social processes that influence vulnerability via the capacities to cope or protect oneself, the situations of vulnerability that people move into and out of over time, and the social construction of vulnerability (Wisner, 2004). Approaches to understanding vulnerability that frame it as a condition overlook relationships and temporal dimensions that influence vulnerability (Kelman, 2018). Adapted from the Pressure and Release model, Wisner et al. (2012) propose "the progression of vulnerability" as a framework explaining vulnerability in the context of disaster risk by relating root causes, dynamic pressures, fragile livelihoods, unsafe locations and hazards.

3.4.2 Methods

The studies reviewed in this research, which is only a snapshot of the vast literature, demonstrate a range of tools and modeling approaches to quantify exposure and impacts. Dottori et al. (2018) use a multi-model framework to estimate human losses, direct and indirect economic damages and welfare losses from river flooding under different temperature and socio-economic scenarios. A study on hurricane Harvey using an energy and moisture perspective to examine the link between ocean heat content and hurricanes finds evidence of a warming ocean supercharging and substantially intensifying the natural hurricane, thus highlighting the unnatural quality of disasters and the importance of adaptation (Trenberth et al., 2018).

Scenario modeling of flood exposure and adaptation has also been used to quantify future flood losses in 136 major cities by 2050 and estimate the required defence standard to address increased risk (Hallegatte et al., 2013). Using 3D and GIS modeling and statistical regression at the global scale, Peduzzi et al. (2012) analyze the trend in mortality risk from tropical cyclones and identify cyclone intensity, exposure, poverty and governance to be important determining factors. These tools, as such, have greatly improved scientific knowledge on how society is contributing to and influenced by climate change and disasters.

Regarding measuring community-level resilience, various frameworks and tools have been developed. Two prominent and well-cited frameworks are Norris et al. (2008) model of four components of resilience – economic development, social capital, information and communication and community competence, and the Disaster Resilience of Place (DROP) model (Cutter et al., 2008). The DROP model, which integrates system attributes with inherent community resilience and vulnerability, enables the consideration of infrastructure, institutional and ecological components. The DROP model was later expanded with a series of indicators for assessing community resilience – social, infrastructure, institutional, economic, and community resilience (Cutter et al., 2010). The thinking behind this model has subsequently been built upon and expanded in several studies, such as one on the connection between wellbeing and resilience to drought in Southern African countries, which used a capacity approach with more weight on the social dimension of community resilience (Brown, 2014).

3.4.3 Knowledge gaps

For the most part, the focus in risk measurement and assessment has narrowly focused on physical hazards and economic impacts. More attention is needed to reflect the complex nature of hazards and risks as well as socia dimensions of vulnerability (Aitsi-Selmi et al., 2016; Rahman and Fang, 2019). Systematic, long-term data is needed to improve measurement. The reviewed literature includes research on both past and future impacts of disasters and climate change, and corresponding responses. Yet, a gap remains in data and knowledge on long-term resilience and vulnerability (Alves and Mariano, 2018; Fatorić and Seekamp, 2017; Klöck and Nunn, 2019; Owen, 2020). This is in sync with the gap of literature on the implementation and outcomes. More systematic, longitudinal data on implementation and monitoring and implementation, as well as research on the sustainability, longevity and suitability of risk management approaches in each context over the long term would enrich the literature.

3.5 Understand the implications of new thinking on hazards

Improvement in hazard knowledge and classification has revealed challenges and gaps in the measurement and assessment of risk and vulnerability. New, updated approaches, models and frameworks are needed to take into account new knowledge and also to expand understanding of the complexity of hazards in the Anthropocene.

3.5.1 Concepts and frameworks

Understanding of hazard has expanded beyond those with natural causes to encompass a broader scope. Early definitions describe hazards as events and phenomena that are well defined temporally and spatially, overlooking processes such as creeping environmental changes (Kelman, 2018). Yet, science has evolved over time to recognize the complex, dynamic nature and the social construction of hazards. In particular, human activities can either contribute to the production of hazards or how a hazard is experienced (Wisner, 2004). The UNDRR now defines hazard as processes, phenomena and human activities that have harmful impacts on health, life, property and social, economic and environmental conditions (UNDRR and ISC, 2020).

As an effort to advance knowledge on hazards, a recent study sought to clarify the scope of all hazards, identifying a total of 302 hazards classified into eight clusters: meteorological and hydrological hazards, extraterrestrial hazards, geohazards, environmental hazards, chemical hazards, biological hazards, technological hazards, and societal hazards (UNDRR and ISC, 2020). The study, however, excludes "complex human activities and processes where it was difficult to identify a single or limited set of hazards, compound and cascading hazards, and underlying disaster risk drivers (such as climate change)" (UNDRR and ISC, 2020, p. 9). This signifies that, despite a shift in the formal definition of hazard and increasing knowledge on interconnected risks, much emphasis remains on more quantifiable and less complex hazards. Chains and synergies among hazards are often subject to neglect in the "still widespread reductionist approach" to hazard analysis and risk assessment (Fakhruddin et al., 2020, p. 226).

3.5.2 Methods

Given recent shifts in the definition and framing of risk and hazard, as outlined above, scholars have called for new tools and approaches to assess and measure systemic or compound risk and hazard. Birkmann et al. (2015) call for the need and potential to link global and local scenario building for better vulnerability analysis. Qualitative scenario assessment using the global WorldRisk Index and local participatory scenario development at the community level demonstrate how vulnerability trends and patterns can be identified and analyzed at different scales and through different lenses for complementary outcomes (Birkmann et al., 2015).

Zscheischler et al. (2018) call for risk assessment and attribution frameworks that explicitly address compound events using an impact-centric perspective, bottom-up methodology that focus on impacts in order to identify underlying drivers and processes. The modeling of compound events is also complex, involving stakeholders' perspectives, the nature and amount of physical variables, spatial and temporal scales as well as the strength of dependence (Leonard et al., 2014).

3.5.3 Knowledge gaps

Appropriate indices and metrices are critical to capture the dynamic nature of and interactions among hazard and vulnerability elements (Fakhruddin et al., 2020; Gallina et al., 2016). There are existing tools to identify and aggregate multiple natural hazard types and assess the vulnerability of multiple targets to a specific natural hazard. However, they do not yet account for other climate change impacts, climate-induced hazards, or other types of hazards (Gallina et al., 2016). Similarly, Fakhruddin et al. (2020) highlight the need to shift towards dynamic vulnerability analysis that accounts for cascading impacts, the temporality of vulnerability, and the complex interplay between coping capacity and sensitivity. More research exploring the merging and combination of different scenario approaches at different spatial and temporal scales for vulnerability assessment is also needed (Birkmann et al., 2015).

3.6 Harness technologies, innovations, data and knowledge for risk reduction

Given the increasing complexity around risk, hazard and vulnerability, as well as depth of knowledge and understanding around risk reduction, science and technology will be essential to informed decision making and innovative solutions to critical challenges. While it is imperative to harness the power of science and technology in all forms, ensuring no one is left behind in the process will be crucial to long-term sustainability.

3.6.1 Concepts and frameworks

Science and technology play an important role in DRR. It has supported the development and implementation of major global frameworks and initiatives and will continue to do so, as recognized in the Sendai Framework for DRR 2015-2030 as well as the Science and Technology Conference on the Implementation for the Sendai Framework (Aitsi-Selmi et al., 2016). The science and technology community has expanded and shifted from operating as a closed group to

playing a more collaborative, co-productive role along with other sectors and in multi- and trans-disciplinary arenas (Shaw, 2020). Six scientific functions have been identified in the context of DRR: assessment of data and knowledge, synthesis of evidence, scientific advice to decision makers, monitoring and review of new information, communication and engagement across sectors, and capacity development for using scientific information (Aitsi-Selmi et al., 2016). Relatively, Priority 1 of the Sendai Framework in understanding risk sees the highest level of engagement and largest role for science and technology compared to the four remaining priority areas (Shaw et al., 2016).

Technological innovations, geospatial tools (e.g. remote sensing; geographic information systems) and big data technologies (e.g. algorithm-based artificial intelligence and machine learning) are rapidly evolving areas of research and development of increasing relevance for disaster risk. Wider applications are emerging, such as related to the capacity to process large amounts of data with to understand the spatiality of risk, exposure and vulnerability, with great potential to have transformative outcomes for DRR and resilience (UK Government Office for Science, 2012).

3.6.2 Methods

A technology-driven approach to DRR has seen an increase in the use of drones, artificial intelligence, robotics, 3D printing, virtual reality and other advanced technologies in both DRR practice and research, such as loss estimation, emergency data management, search and rescue operations, and research and education (Shaw, 2020). Remotely sensed data, real time digital data as well geo-information tools and techniques offer rich inputs for improving the assessment and understanding of complex risks (Rahman and Fang, 2019). GPS, GIS and hand-held portable devices are some of the tools available to complement crowd sourcing data (Aitsi-Selmi et al., 2016). It is, however, important to ensure that data collected using advanced technologies, such as satellite-based spatial data, as well as computer-based technological packages are easily accessible to relevant stakeholders and young researchers (Rahman and Fang, 2019).

3.6.3 Knowledge gaps

Science and technology needs to take into account the complexity of hazards and their interactions, addressing compound risk, NaTech, systemic risk as well as multi-hazards and all hazards (Aitsi-Selmi et al., 2016; Shaw, 2020). More research integrating human behavior and social norms and networks is needed, particularly in in risk perception and risk assessment (Eiser et al., 2012). Eiser et al. argue that the role of behavioral science in DRR has received increasing recognition, yet research-investigating determinants of human behavior within and across social groups remain superficial. More research on how warning systems and policies are perceived and what makes them effective is also needed. Similarly, reviewing the literature on global governance in the context of globally networked risks, Galaz et al. (2017) suggest that the current debate on global risk governance overlooks legitimacy, or people's normative evaluation of international decision making. Whether the public deems institutional arrangements legitimate is critical to their effectiveness.

Traditional, Indigenous knowledge is one category of technology that will remain relevant and critical as technology continues to advance (see Shaw, 2020). It is thus important that the science and technology community engage and collaborate with local communities early on through processes of co-design and co-delivery to ensure the effectiveness, relevance and applicability of outcomes (Shaw, 2020). Information technology can also play important role in scaling up community-based achievements in sustsainability (Aitsi-Selmi et al., 2016)

3.7 Foster inter-disciplinary and multi-stakeholder collaboration for solutions to risk challenges

The importance of and push for inter-disciplinary, transdisciplinary and multi-stakeholder collaboration have been highlighted across numerous areas of disaster science. Undeniably, reducing disaster risk in the context of an increasingly interconnected Anthropocene age is not feasible without joint efforts and consideration of diverse epistemologies. One concrete avenue highlighted in the literature is the integration of DRR with climate change adaptation (CCA), where the links are clear yet much potential is yet to be realized. Capitalizing on synergies and refining disciplinary characteristics of disaster science are needed to ensure fruitful collaboration.

3.7.1 Concepts and frameworks

DRR-CCA integration

As both DRR and CCA are concerned with questions of vulnerability, resilience, risks, hazards, and uncertainties, integrating DRR and CCA has been gaining ground in research and policy (Hore et al., 2018; Islam et al., 2020; Kelman,

2015). Since disaster risk is interpreted as a combination of hazard and vulnerability, climate change can drive or diminish hazards while also influencing vulnerability (Hore et al., 2018; Kelman, 2015). Climate change mitigation and adaptation initiatives themselves can also influence disaster risk (Hore et al., 2018). Thus reasons for integrating CCA and DRR include sharing resources and data, avoiding duplicated efforts and missed opportunities as well as complementing sustainable development efforts (Birkmann and von Teichman, 2010; Hore et al., 2018; Kelman, 2015). Moreover, as DRR has a longer history of being embedded within development and evolving from the hazard paradigm to the vulnerability paradigm, failure to integrate and encompass DRR knowledge and practice in CCA has led to CCA being a scapegoat for DRR and developmental failures (Hore et al., 2018).

3.7.2 Methods

In order to increase synergistic effort, the research community has pushed for the conceptual integration of CCA as a part of DRR within the larger context of sustainable development (Birkmann and von Teichman, 2010; Hore et al., 2018; Kelman et al., 2015). Birkmann and von Teichman (2010) outline the possibility to integrate CCA into each of DRR cycle of mitigation, preparedness, response and recovery and reconstruction.

Climate change mitigation, on the other hand, is conceptualized as a subset of sustainable development according to Kelman (2015) and as a subset of pollution prevention, under the umbrella of sustainability and development, according to Hore et al. (2018). Hore et al. (2018) also note the overlaps between mitigation and adaptation, as well as between pollution prevention and DRR. Furthermore, scholars have also explored CCA-DRR integration from a governance perspective, through which Forino et al. (2015) propose a conceptual framework linking social, market and state actors through co-management, public-private partnership and private-social partnership. Alternatively, Linnerooth-Bayer and Hochrainer-Stigler(2015) adopt the financing lens and argue that risk financing and risk reduction, as subsets of disaster risk management, can target different layers of risk, thus contributing to and complementing CCA.

3.7.3 Knowledge gaps

The siloed characteristics of disaster and climate change prevail (Birkmann and von Teichman, 2010; Hore et al., 2018; Islam et al., 2020). For example, while both DRR and CCA seeks to reduce vulnerability, so far the two fields have not converged on a mutual definition of the term. Demarcations have been ingrained through long-term processes and debates, hence the separate agreements of 2015 resulting from historical processes and political purposes that render merging them undesirable (Kelman, 2015).

Differences in governance, scales, knowledge and norms, as well as the lack of funding coordination and political influence, present great challenges against CCA-DRR integration (Birkmann and von Teichman, 2010; Islam et al., 2020). Furthermore, integration at the conceptual level often faces an operational gap (Islam et al., 2020). For example, the Sendai framework mentions integrating climate change but does not specify operational details (Kelman, 2015); SDG Goal 13 also makes the connection between CCA and DRR with no details on how it will be realized (Forino et al., 2015).

In addition to integrating DRR and CCA, fostering inter-disciplinary and multi-stakeholder collaboration in DRR also requires further improvement in the disaster and climate change literature's disciplinary characteristics. Overall, the literature spans a wide range of disciplinary fields. Some areas need more integration across disciplines, while others may benefit from a deeper scope of analysis. For example, the DRR literature is abundant in disciplinary and multidisciplinary works, but the complex interplay among risk factors and systemic risks require more co-produced, transdisciplinary knowledge production (Ismail-Zadeh et al., 2017). The research on climate justice, a cross-cutting theme in nature, on the other hand, insists that existing publications are dispersed across such a large number of journals that more tune-fining is needed to identify the most appropriate channels to communicate research findings (Alves and Mariano, 2018).

3.8 Support regional and national science and knowledge for policy and action

The literature reviewed covers wide and diverse geographical regions; however, there appears to be a geographical imbalance in terms of both where data are collected and where research outputs are produced. An earlier review of disaster science literature published from 2012-16 found that China, USA and Japan are by far the most prolific countries for publishing scholarly literature (Elsevier, 2017). There may be some correlation between scientific output and disaster loss, as research tends to focus on major disaster events and risks with high relevance for the context (e.g. earthquakes and tsunamis in Japan; floods and droughts in China). However, there may still be a disconnect between

where disaster impacts are felt and where research is conducted, particular in low and middle income countries (LMICs) (Elsevier, 2017).

The adaptation literature also bears a degree of geographic imbalance. For example, most works on cultural heritage adaptation as well as on climate justice are from scholars in Europe and North America (Alves and Mariano, 2018; Fatorić and Seekamp, 2017); more research on adaptation effectiveness focuses on Asia (dominated by studies on China) and North America (dominated by studies on the U.S.) (Owen, 2020); and adaptation research in SIDs tend to focus on the Pacific, core and near core islands (Klöck and Nunn, 2019). Similarly, the review of CCA-DRR integration research notes limited geographical range targeting key knowledge gap, i.e. policy integration studies are limited to few countries such as Australia, Thailand, Zambia and Indonesia (Islam et al., 2020). Testing different integration frameworks in various contexts and their comparative analysis are missing from the literature (Islam et al., 2020).

Overall, more research in/on/from the periphery and developing and underdeveloped countries are needed. One of the reasons for the imbalance may be the lack of data in remote and under-resourced areas, yet in every region there appears rooms for different thematic focuses.

4 Discussion and conclusions

In this paper, we have provided an overview of the state of current knowledge on disaster risk science, covering the framings, approaches, tools, and knowledge and data gaps. Disaster risk science is constantly evolving, its concepts and framings refined, contested, and redefined across diverse and inter-related disciplines. In the context of increased global connectedness, the evolution of risk understanding from 'natural' to 'systemic' is apparent. It is central to the framings of risk, hazard, vulnerability, resilience, and adaptation, among others, and their cascading, compound, and interacting impacts, which are at the core of this review. The increasing role of the social dimensions of risk and vulnerability has foregrounded local, traditional, and Indigenous knowledges and methodologies as critical components of disaster risk science.

Innovations in scientific methods and technologies have enabled new ways of knowing, understanding, measuring, and assessing. More than ever before, the confluence of these trends and progress calls for meaningful and inclusive collaboration across scales, geographies, and disciplines and progressive governance approaches to risk reduction and management.

Through this exercise, gaps and priorities are emerging with implications for future research. First and foremost, a growing disconnect between knowledge and action is becoming apparent. The desired shift to ex-ante from ex-post approaches to risk management, for example, has not mirrored equally between disaster risk science development and policy and practice. One reason may be the lag between conceptual and theoretical advances and grounded knowledge and empirical data; another the lack of effective science to policy communication. Second, a holistic understanding of risk is lacking. While there is a plethora of quantitative and qualitative approaches to understand the manifestation, perception of and responses to risk, there is yet no integration of approaches that also account for diverse, place-based ontologies and epistemologies. Third, across scales and between regions and nations, knowledge production suffers from significant imbalance and disparities. A future research agenda needs to be conscious of power relations informing and informed by disaster risk science and make space for subalterns studies and locally-produced knowledge to drive progress.

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6 Annex

This box is provided for the authors to further illustrate how this study contributes to IRDR research objectives/ SFDRR targets/ SDGs/ Climate Goals/ Science and technology roadmap actions if applicable.

1. How does this study contribute to IRDR research objectives? (50-150 words)

2. How does this study contribute to SFDRR targets? (50-150 words)

3. How does this study contribute to SDGs and/or Climate Goals targets? (50-150 words)

4. How does this study contribute to S/T roadmap actions? (50-150 words)

Main recommendations to DRR policy if not yet highlighted in the main texts:

6.1 IRDR Box

Indication of contribution to[2]

IRDR Sub-objectives	(at least one)
SFDRR targets	(at least one)
SDGs and/or Climate Goals and targets	(at least two)
S/T Roadmap actions	(at least one)

Disclaimer of IRDR

Endnotes

1. Scientific discipline assignment is done automatically by Scopus.
2. Please refer to the hyper-link for the details of each statement. Please fill in with just the number of the item, for example, IRDR sub-objectives: 2.1. Please explain how this study contributes to these targets/objectives in details in the box after the reference part.

Appendix 4 Indicative Research Priorities in alignment with Research Priority Areas (outlined in Section 5).

These specific research issues and questions are listed here to ensure that the individual inputs made as part of the consultation process are acknowledged and accessible. Many of these are at least partly incorporated into the 9 main research priorities in the Agenda. In conjunction with the main Priorities, these statements can form the basis of further engagement with diverse stakeholder groups on research gaps, needs and funding. Note that these notes are not comprehensive and input that fully aligns with the 9 priorities is not included here as it is already included.

Priority Area 1: Understanding risk creation and perpetuation: systemic, cascading and complex risks.

Indicative Priorities

- Understand the major risks to humanity in all global contexts.
- Better understand how risk is created and perpetuated.
- How is risk changing in diverse global contexts towards systemic, concatenating, compounding and cascading risk vulnerabilities and exposure?
- Defining, identifying, assessing and managing existential risks.
- What are the primary causes / triggers of cascading and complex risk?
- How can science and research help us better understand complex interdependencies and tipping points (i.e. between regular hazards and disasters; simple risk to complex and systemic risk)?
- How can capacity be built across research and practice in areas of risk science, climate change and sustainable development?

Priority Area 2: Addressing inequalities, injustices, marginalisation and vulnerabilities.

Indicative Priorities

- Enhance understanding of how risk is experienced in complex ways in different communities, acknowledging that already vulnerable communities are generally impacted disproportionately by adverse events (for example, the COVID 19 Pandemic).
- Better understanding of the root causes of deep vulnerability is needed.
- Risk science should better support sustainable and equitable development.
- Better understand variable resilience and response capacities at diverse scales (local, national, regional) across all global regions.
- Can risk science be augmented to better support social change (i.e. behaviour, investment, financial decision making etc) to rapidly counteract intensifying dimensions of risk and the inequitable nature of exposure and vulnerability?
- Risk reduction needs to be considered much more comprehensively from the perspective of social, economic and environmental dimensions, across a range of scales.

Indicative Priorities

- Ensure the equitable inclusion of alternative knowledge systems, beyond traditional forms of science, in developing solutions and decision-making.
- Ensure a global focus on social justice and equity with regard to risk, vulnerability and exposure. How can resilience be enhanced to ensure justice and equity (e.g. via the SDGs)?
- How can we develop an ethos of mutual enrichment and a formative dialogue between diverse knowledge carriers, at all levels of risk governance?
- Plural solutions: Emphasis on diversity of implementation, solutions development and communication tools to meet needs of diverse groups (communities, areas and sectors of practice, disciplines of research).
- How can risk science encourage and empower bottom up/grassroots and community action?
- How can marginalised and informal groups (advocacy, activist etc.) and their knowledge be made visible and legitimised within the diverse context of risk thinking and practice?

Priority Area 3: Enable transformative governance and action to reduce risk.

Indicative Priorities

- Enhance coherence across UN frameworks, agreements, organisations and objectives. How can improving synergies across major global agreements better support coping with complex and systemic risk?
- How can enhanced coherence support trans-disciplinary risk science outputs and impact?
- Undertake a mapping exercise to understand current state of global risk governance.
- Develop governance mechanisms for systemic risk and support-required transitions.
- What sort of governance arrangements might suit existential risks?
- Support risk informed decision-making and practice (across all sectors, disciplines and within communities).
- Encourage investment (broadly defined to include private and public sector, economic, socio-cultural etc.) in ways that reduces risk vulnerabilities and exposure from a global scale, down the local levels where events are experienced in disparate ways.
- Develop mechanisms to incentivise risk and resilience based decision making in policy and practice across all sectors
- Develop tools that allow practitioners to robustly justify risk-based thinking when defining de-velopment strategies (whether for poverty reduction and social development, infrastructure and urban development, or other focus areas).
- What enablers are required to better implement science into policy and practice (i.e. action)?
- How can science be more 'user friendly' (i.e. in the private sector, by policy makers, in com-munities)?
- Can risk science support the strengthening of risk-based decision-making through market-based incentives?
- Foster better relationships and networks between risk science and private sector communities.
- How can risk science support improved urban resilience, recognising that population growth and urbanisation are increasing globally?

Priority Area 4: Understanding the implications of new thinking on hazards.

Indicative Priorities

- How does armed conflict and other forms of violence intersect with other "natural" and technological hazards? How does it affect exposure and vulnerability?
- Covid and other pandemics and epidemics provides a new context for understanding hazards.
- Has the halting of parts of globalisation during the Covid pandemic affected the generation of vulnerabilities – positively and negatively?
- Much more effect is needed to understand emerging hazards and combinations of hazards.

Priority Area 5: Harness technologies, innovations, data and knowledge for risk reduction

Indicative Priorities

- How can the negative impacts and uses of new technologies be ameliorated?
- What new hazards or combinations of hazards are being created by new and emerging technol-ogies?
- Keep abreast of emerging and future technologies to ensure maximum relevance for alleviating risk vulnerability and exposure.
- Can technology enable social change towards risk awareness and behavioural transition at a global level?
- How can technology be used encourage the uptake of risk-based information, including in pop-ulations and communities that are currently isolated from risk based thinking and decision-making?
- How can modelling be enhanced to reduce levels of uncertainty and maximise benefit to re-ducing societal risk?
- Can risk science contribute to enhancing current and/or developing new models that can cope with variables of systemic and complex risk?
- Is there potential to develop an open access digital platform, with crowd-sourcing capability to promote transformative action and build societal risk awareness and resilience?
- How can technology support trans-disciplinary and multi-sector dialogue and knowledge shar-ing?
- How can technology strengthen linkages and knowledge sharing to improve the risk exposure of emerging economies and geopolitical complex countries (such as enhancing capacity and knowledge sharing linkages to the global south)?

Priority Area 6: Support regional* and national science and knowledge for policy and action.

*As per World Bank Regional Units (worldbank.org)

Region	Indicative Priorities
Africa	➤ Research policy and technical capability Enhance science and research policy with support of donor agencies for effective sci-ence-policy interface to support development. ➤ Governance Transparent and accountable mechanisms of DRR and CC governance. Potential for adoption of new approach: 4Ps (Public Private Population Partner-ship) to strengthen accountability and ownership. ➤ Transboundary risks Transnational/boundary DRM is required, and should be supported by joint DRR research initiatives.
East Asia and the Pacific	➤ Support alleviating issues with coherence and governance. ➤ Support the implementation of science into policy and governance mechanisms. ➤ Research work needs to be 'ready to implement' (have a implementation methodology the explains the 'how to'). ➤ Cross-disciplinary integration ➤ Engineering should be integrated with DRM. ➤ Multidisciplinary but focused on regional and local projects through to implementation. ➤ Climate Change is a major concern, especially in the Pacific, with associated complexities of mitigation, retreat, climate diaspora. ➤ Climate and Environmental Governance and Justice - 'Who speaks for us?' - Pacific voices under heard on the international stage, even though they are bearing the brunt of emissions from other places. ➤ Complex donor and recipient relationships especially associated with disaster risk finance and recovery mechanisms.
Europe and Central Asia	➤ Coherence (science and governance) - Enhance a pan-European approach that is highly integrat-ed. ➤ Emphasis on New and Emergent Technologies for 'linked up' systems that lead from knowledge development to solutions and informed decision making. For example, an open access digital platform with crowd-sourcing capability could promote transformative action to build commu-nity resilience as the climate changes. ➤ Match the scale of science information to scale of science delivery and decision-making. ➤ Public investment is major force of transformation in the coming decades. DRM should be a core to these investment principles, and this should integrate sectors (i.e. science, public and private sectors).

Region	Indicative Priorities
Latin America and the Caribbean	➤ Vulnerability and resilience – capacity building ➤ Enhance local capacities through social Innovation ➤ Emphasis on incorporation of non-scientific knowledge sys-tems to ensure legitimacy of decision-making and solu-tions, and to encourage local buy-in and support for transi-tion. ➤ Development of methodologies for embedding DRM tech-niques into sectoral and territorial planning. ➤ Development of analytical DRM models that bind together disaster risk modeling, engineering, and risk finance strate-gies. ➤ Climate change and intensification of disaster events in vulnerable SIDS. Transnational DRM initiatives. Many of the risk contexts transcend boundaries. Frameworks to address transnational challenges (i.e. flooding-related risk) are lacking. ➤ Incorporation of non-scientific knowledge systems. LAC represents dozens of autonomous communities, with their own interpretations of the world, knowledge systems and value tradition for under-standing, coping and interacting with nature. This knowledge remains excluded from formal and scientific spaces. ➤ Generate interaction spaces between 'formal' science and other communities of practice.
North America and Canada	➤ Sea Level Rise (Florida, Louisiana and other coastal low lying areas especially influenced by Hur-ricanes). Socially challenging questions relating to managed retreat, insurance mechanisms (i.e. who is accountable / pays) and mitigation. ➤ Key questions on effective governance. ➤ Institutional complexities. ➤ Diversity in decision-making issues.
South Asia	➤ Complex geopolitical and trans-boundary context. ➤ Region of high population growth, limited capacity and prone to hazards due to high relief, ac-tive tectonics, complex geological settings and sensitivity to climate change. ➤ Some highly developed and modernising economies, others that are far less developed. ➤ Require enhanced risk assessment and co-ordinated management mechanisms, where often disasters are trans-boundary and geopolitically complex. ➤ Need to include diversity within decision-making. ➤ More research into the integration of science, governance and civil society at local, regional, na-tional scales.

Priority Area 7: Supporting just and equitable transitions, adaptation and risk reduction.

Indicative Priorities

- What are the primary risks in transition, and what can be done about these risks?
- Ensure that the risks inherent in hazard and risk reduction are identified and managed.
- We need to learn and adapt rapidly from the short experience with "just transition".
- How does Covid and other pandemics and epidemics affect just transitions?

Priority Area 8: Measurement to help drive progress.

Indicative Priorities

- Is it achievable to define and adopt standardised ways of measuring risk?
- Is an entirely new approach to measurement needed for global risks?
- How can global risk literacy be increased measurably within in the next decade?
- Can the risk science community collectively define an aspirational goal for 'measurable' im-provement of risk literacy/ awareness, and associated behavioural transformations, at a societal scale?
- Is risk science able to support the development of mechanisms to enhance and incentivise soci-etal behavioural change towards risk awareness (i.e enhanced linkages with financial incentives and insurance mechanisms)?
- There is a lack of agreed to indicators of exposure and vulnerability that capture the issues faced by marginalised and vulnerable people and communities. Can risk science sypport the development of such indicators? An example here is the incorporation of the social vulnerability index (SoVI) into (USA) FEMA's National Risk Index for use in hazards planning and analy-sis. https://www.fema.gov/flood-maps/products-tools/national-risk-index

Priority Area 9: Foster multi-stakeholder collaboration for solutions to risk challenges.

Indicative Priorities

- Develop mechanisms that support trans-disciplinary and multi-sector understandings of risk, vulnerability and exposure.
- Improve collaboration across disciplines, research communities and sectors.
- Develop mechanisms that support trans-disciplinary and multi-sector approaches enhance science delivery, inform decision-making, and are effective for building just and equitable solutions.
- Harness the enormous upsurge in on-line connections and collaborations during Covid to help include groups normally excluded from face-to-face meetings.
- Broaden and deepen trans-disciplinary and cross-sector networks of dialogue and knowledge sharing.
- Developing interconnections to broaden and enhance risk science delivery and impact
- How should risk science be communicated and delivered to non-scientific communities?
- What are the appropriate ways to engage with communities that are currently isolated from risk-based thinking?
- Identify institutional gaps, strategic gaps and epistemological gaps, and develop solutions to overcoming knowledge to action challenges.

Appendix 5 The IRDR 2008 Science Plan summary

The 2008 IRDR Science Plan:

On the commencement of the IRDR a science plan (International Council for Science, 2008) was developed to guide the work of the program. This plan is at the end of its intended life, and a new plan has been developed. The IRDR Science Plan was seen as a definitive document to guide the work of the IRDR Community. It was not designed to evolve or take account of the changing contexts of risk and disasters, and perhaps could not have foreseen the speed and extent of change.

As discussed above, the decision was taken to look well beyond the traditional DRR community in doing so.

- The IRDR Science Plan was designed based on the HFA, and developed into a Strategic Plan after establishment of the IRDR.
- The original three research objectives and three cross-cutting themes were framed into actions in six goals: Goal 1- Promoting integrated research, advocacy and awareness-raising. Goal 2- Characterizing hazards, vulnerability, and risk. Goal 3- Understanding decision-making in complex and changing risk contexts. Goal 4- Reducing risk and curbing losses through knowledge-based actions. Goal 5- Networking and network building. Goal 6- Research Support.

The 2008 IRDR Science Plan sought an integrated international science focus on hazards related to geophysical, oceanographic and hydrometeorological trigger events. In particular, this included, but was not limited to investigating: earthquakes; volcanoes; flooding; storms (hurricanes, typhoons, etc.); heat waves; droughts and fires; tsunamis; coastal erosion; landslides; and aspects of climate change. The Science Plan initiated a much more prominent international focus on researching the effects of human activities on creating or enhancing hazards, including land-use practices.

In 2005, the predecessor ISC (then ICSU) Scoping Group emphasized that:

> *There is a great shortfall in current research on how science is used to shape social and political decision-making in the context of hazards and disasters. These issues also highlight the need for more systematic and reliable information on such events.*

Consequently, as well as the generation of new science and data, there was a recognised need for the 2008 Science Plan to guide improved coordination and integration with regard to global data and information across hazards and disciplines.

The focus within the Science Plan on risk reduction, understanding risk patterns and risk-management decisions and their promotion, required emphasis on research at global, regional and local scales. Three broad research objectives were set out as follows:

Objective One: The identification, characterisation and assessment of risks from natural hazards on global, regional and local scales. This included the need to address gaps in knowledge, methodologies and types of information that were preventing the effective application of science to averting disasters and reducing risk.

Objective Two: Understanding effective decision-making in the context of risk management. This included clarification of what 'good' decision-making looks like in complex and changing risk contexts; and an enhanced understanding of how human decisions and the pragmatic factors that constrain or facilitate such decision making can contribute to hazards becoming disasters and/or may mitigate their effects.

Objective Three: Reducing risk and curbing losses through knowledge-based actions. This objective required integration of outputs from the first two objectives to implement and monitor informed risk reduction decisions and through reductions in vulnerability or exposure to hazards.

Three crosscutting themes supported the Science Plan's objectives, including: capacity building (with emphasis on mapping capacity for disaster reduction and building self-sustaining capacity at various levels for different hazards); case study development and demonstration projects; and assessment, data management and monitoring of hazards, risks and disasters.

Based on the preceding objectives and themes, the IRDR Planning Group identified the major programmes and projects that already existed in the field of natural hazards and disasters. In addition, the Planning Group identified and built capacity in new project areas through consultative working groups.

A Framework for Global Science in Support of Risk-informed Sustainable Development and Planetary Health

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International Science Council
IRDR Integrated Research on Disaster Risk
UNDRR UN Office for Disaster Risk Reduction