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Coming to Terms with Deep Uncertainty in the Study of Climate-Related Displacement

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Abstract

On average, an estimated 20 million people each year are displaced by climate-related hazards. This number will increase in coming years due to global warming, sea level rise, and rapid population growth in areas highly exposed to floods, storms and droughts. Future levels of displacement will depend on future greenhouse gas emissions, future development trajectories in low- and middle-income countries, and future government migration and mobility policies. Given the rapidity of atmospheric change, there are likely also ‘unknown unknowns’ factors that could cause unexpectedly large and/or sudden displacements. This article reviews what scholars know about how climate affects displacement; what is known or suspected but important data are lacking; and other considerations that are understood poorly or not presently observable. Particular attention is given to reflecting on how scholars can advance research on climate-related displacement under conditions of deep uncertainty, with suggestions on ways to shed light on ‘unknown unknowns’.

Keywords

Climate Change; Displacement; Natural Hazards; Uncertainty; Migration

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Introduction

Of all the consequences of anthropogenic climate change that might occur, one of the worst possible cases for human society would be repeated population displacement events of scales so large they cause widescale political and economic disruptions. Such outcomes are avoidable through transformation of the global energy economy using already-available technologies, wiser land-use and infrastructure planning, and greater efforts to achieve sustainable economic growth in low- and middle-income countries. The international community's lethargic progress in reducing greenhouse gas emissions – which increase the frequency and severity of floods, storms, wildfires and other extreme weather events in many regions, and accelerates the rate of mean sea level change (Arias et al. 2021) – means that with each passing year, the risk of larger and more widespread climate-related displacements (CRD) grows. For researchers who specialize in the study of CRD, and for decisionmakers who must plan for it, key questions that require greater consideration include:

- exactly how likely are such outcomes?
- how potentially large could they be and how frequently might they occur?
- where and when would they be most likely to occur, and where would people go?
- at what size, scale, and/or frequency would displacement events become too great to manage or recover from, and thereby trigger national, regional and/or global socio-economic crises or collapse?

We currently lack sufficient data to answer these questions with any great confidence. Worse still, there is deep uncertainty about how human populations will be affected by and respond to a rapidly changing climate and an atmosphere whose composition is unlike anything humans have ever experienced. We are not entirely sure what the climate will look like and how it will behave by the end of this century, and we are not sure how ocean circulation patterns will respond to the excess heat and meltwater they will receive. Indeed, the uncertainty in some areas is so great, we are perhaps not even asking the correct questions or seeking answers in the best way. While current inaction on the root causes of climate change might lead to population displacements and societal breakdowns on scales not seen since the 1930s and 1940s (then caused by the combined effects of the Great Depression, colonialism, and fascism), there are also reasons to be optimistic: with renewed commitment to meeting the UN Sustainable Development Goals (SDGs) we could potentially achieve multilateral cooperation, collective actions, and societal transformations that eliminate poverty, preventable illnesses, civil unrest, environmental degradation, and involuntary population displacements. For obvious reasons, as researchers and citizens we want to identify the pathways that expedite optimistic outcomes and mitigate the frightening ones.

How do we as researchers identify such pathways in an environment of deep uncertainty? One way of framing the challenges in clear and colloquial terms is to draw upon an unlikely source: the late Donald Rumsfeld (1932-2021), who served as Secretary of Defense for two US presidents. Rumsfeld is perhaps best known to the public for comments he made immediately prior to the US-led invasion of Iraq in 2003, in which he described how military decisions are made (at least to his thinking) under conditions of uncertainty. He described the intelligence information available to decisionmakers as consisting of 'known knowns' (i.e., data collected through direct observations and its accuracy verified), 'known unknowns' (i.e., potential risks that have been identified but are poorly understood, and require more data than is currently unavailable), and 'unknown unknowns (i.e., things that are happening or that might possibly happen but are not identifiable given current information – a loose synonym for 'deep uncertainty'). A key behind-the-scenes actor in American geopolitics from the early 1970s through the early 2000s, Rumsfeld is a highly controversial figure who influenced decisions that led to invasions, conflicts, and human rights crises. In bringing his name up here I am not celebrating nor commenting upon his political career, but am simply borrowing his clear, accessible terminology about categories of uncertainty and applying it to questions of how we as researchers can go about assessing the potential for catastrophic CRD in a climate-disrupted future. The remainder of this article undertakes two tasks. First, it summarizes what CRD researchers are relatively certain about with respect to climate-related displacements (i.e., our 'known knowns'), factors that will potentially influence future climate-related displacement but for which we currently lack adequate data (i.e., our 'known unknowns'), and things about which we can at best only speculate might happen and at worst could actually be happening or about to happen without our realizing it (i.e., our 'unknown unknowns'). This is followed by reflections on how we might begin to better imagine what the unknown unknowns might potentially be and how we can move forward conducting research under conditions of deep uncertainty.

Background

Not so long ago, bleak scenarios about dystopian, climate-disrupted futures were the domain of popular writers of fiction and non-fiction, security analysts, think-pieces generated by multilateral organizations and NGOs, and the occasional Hollywood disaster movie. Scholarly concerns about the impacts of environmental factors on human populations date back to Thomas Malthus's 1798 essay on population principles (Malthus [1798] 2023), with Malthusian concerns about the potential consequences of rapid human population growth, natural resource depletion, and global food supplies experiencing a revival in the late 1960s with publications including *The Tragedy of the Commons* (Hardin 1968), *The Population Bomb* (Ehrlich 1968), and *Limits to Growth* (Meadows et al. 1972). These studies raised concerns about dystopian futures but did not systematically address what currently happens and what might happen in the future in terms of population movements resulting from adverse environmental conditions. This latter consideration started getting attention in the 1980s with publications explicitly focusing on 'environmental refugees', influential ones including a booklet produced for the UN Environment Programme (El-Hinnawi 1985) and a report by the now defunct Worldwatch Institute thinktank (Jacobson 1988). These were followed by a highly influential 1994 *Atlantic Monthly* article entitled, 'The Coming Anarchy' (Kaplan 1994) that identified environmental degradation as a key factor in conflict and refugee movements in West Africa and warned of more to come in a changing climate. Kaplan's article became required reading in the US administration of President Bill Clinton and Vice-President Al Gore, the latter going on to make his own contributions on the bleak consequences of inaction on climate change through his book and movie, *An Inconvenient Truth* (Gore 2006).

The small number of academic scholars who in the 1980s and early 1990s were investigating and warning of future climate-related conflicts and displacements – such as Thomas Homer-Dixon (1991), Arthur Westing (1992), and Vaclav Smil (1995) – were often criticized for being alarmist, having unnecessarily Malthusian outlooks, or seeking to revive early 20th century environmental determinism (see Vigil 2022 for a review of this last concept). Perhaps the best-known environmental refugee scholar of that era was the late ecologist Norman Myers (1934-2019), who warned that environmental degradation was generating conflicts and refugee flows around the world (Myers 1986) and predicted that, in the absence of concerted effort to reverse the mounting ecological damage of human activity, hundreds of millions of people would be displaced by environmental hazards by the mid-21st century (Myers 1997). Other scholars – including myself (see Brown & McLeman 2009) – sought to temper the bleak prognostications of Myers and counterparts by seeking out more explicit definitions of what constitutes environmental migration and displacement (and shunning the use of the term 'refugee' altogether in this context) and demonstrating through empirical evidence (typically acquired through case studies; see Obokata et al. 2014) the complexity of causal linkages between environmental events, adaptation, and migration, and thereby identifying many opportunities for intervention that, if acted upon, would avoid environmentally linked conflicts and displacements (see McLeman 2016 for review).

With the passage of time, Myers's warnings are looking to be more prescient than alarmist. For the past fifteen years the Geneva-based Internal Displacement Monitoring Centre (IDMC) has been collecting annual statistics on the number of people displaced within their home countries each year by conflicts and by environmental hazards. Their statistics suggest that between 2010 and 2024 an average of roughly 20 million people each year have been displaced by weather- and climate-related hazards – primarily floods and storms, but also by droughts and wildfires – with the largest amount of CRD occurring in coastal areas of Asia (IDMC 2024). The mean average is less informative than the considerable range of interannual variability (2022 seeing more than 30 million climate-related displacements worldwide, 2023 only 7.7 million) and the fact that the mean appears to be increasing. Some of the variability and upward trend might be attributable to improvements and refinements in IDMC's data collection methods over the measurement period, but on the whole, it appears we could be in the early stages of what Myers predicted: an accelerating rate of CRD. If so, what will happen next?

What we know (or think we know) about climate-related displacement (CRD)

1. WE KNOW THAT THE CAUSAL FACTORS OF CRD ARE CONTEXT SPECIFIC

Much more is known today than in the 1980s and 1990s about the complex chains of causality between environmental events, migration and displacement outcomes, and the mediating effects of any number of cultural, demographic, economic, environmental, political and social processes that are continually changing, interacting with one another, and operating across multiple scales of space and time (Cissé et al. 2022). We recognize that climate-related population movements occur within a continuum of agency, from voluntary to involuntary, which is in turn influenced by the nature and severity of the climatic hazards to which individuals, households and communities are exposed and their vulnerability and capacity to cope with and adapt to such hazards (McLeman et al. 2021). We know that any number of possible migration and displacement outcomes might arise at any given time and place when adverse climate events occur; sometimes these cause large numbers of people to flee the area, some to later return and others not, and in some cases new migrants may actually be drawn into the affected area (Veronis et al. 2018). Some people might want to flee but lack the means to do so (known as 'involuntary immobility'), while others may resist moving even when it might be safer to do so due to strong cultural and socio-economic attachments to that place (Zickgraf 2018; Bro et al. 2024). The steady growth in empirical studies of how climatic events affect population movements has often revealed contradictory findings when comparisons are made within countries (Thiede & Gray 2016) and across countries (Gray & Wise 2016), leading researchers to the conclusion that CRD events observed at a given place and time are a product of interactions of climatic and non-climatic processes specific to that particular context. In this article I focus principally on uncertainties about future displacement (i.e. involuntary migration) attributable directly or indirectly to climate hazards, recognizing the inherent definitional blurriness of causality and voluntarity.

2. WE KNOW THERE ARE CERTAIN COMMONALITIES ACROSS ALL CURRENT EXAMPLES OF CRD

Despite this context specificity, there are some attributes of CRD that can be generalized (McLeman 2014). The more severe the climate event and the more sudden its onset, the greater the potential for people to be displaced from the exposed area. In the case of severe, sudden onset events – extreme storms, floods and wildfires being the most obvious and common examples – the resulting movements tend to follow a typical progression. There is a short period of evacuation and displacement immediately after the event, during which people are simply seeking safety and shelter. Once the storm or fire has passed or the flood waters have receded, most of those displaced will seek to return and rebuild their homes and livelihoods, if possible. The extent of damage to homes and critical infrastructure is an important determinant of which households will resume living in the affected area and which ones will relocate elsewhere. This in turn means that home ownership, access to insurance, and the speed with which authorities rebuild critical infrastructure help determine which families return and which neighbourhoods are reoccupied, with low-income people and those who rent their accommodations most likely to be unable to return. Slow-onset climate events such as droughts harm livelihoods but do not damage housing stocks, so households have time to implement strategies for coping with the impacts of the climate event that are less disruptive than relocating (Hermans & McLeman 2021). It is only once the socio-economic impacts of the slow-onset event become so great or persist for such an extended period that these non-migration strategies start to fail and people start to move. This movement falls into a grey area between voluntary and involuntary migration (i.e. displacement), and initially some members of a household may move (to seek out income opportunities and reduce the number of mouths to be fed) while others remain behind in the drought-affected area. Should drought conditions persist, and governments and other organizations be unable or unwilling to provide necessary humanitarian assistance, widescale displacement of people from the affected area may ensue, although such situations occur infrequently, and typically only in regions plagued by violence and civil conflict, such as Somalia (Thalheimer et al. 2023).

3. WE KNOW WHERE MOST CLIMATE-DISPLACED PEOPLE GO AND WHY THEY GO THERE

We know that when people must move in the face of a climate hazard, they go most often to places that are geographically proximate, especially places where they have pre-existing family, social, economic or cultural ties (Cissé et al. 2022). We also know that institutions play a critical role in (1) implementing mechanisms that reduce the potential for people to be displaced from their homes by climatic hazards and (2) providing the resources households and communities need to recover from adverse climate events. Where institutions are strong and capable in these areas, CRD tends to be low and temporary. Conversely, where institutions are weak, incompetent, or corrupt, households must recover and adapt by relying on their own resources, meaning people are more likely to move farther afield and/or move away indefinitely (McLeman & Smit 2006; Black et al. 2011). For example, in the wake of 2017's Hurricane Maria, a feeble and inadequate relief effort on the part of US authorities led hundreds of thousands of displaced Puerto Ricans to move to Florida and New York (Straub 2021; Clark-Ginsberg et al. 2023).

We know that most CRD currently takes place within countries, and that when climate-displaced people do move internationally, it is typically between countries that share a border or are within the same geographical region. This again reflects the economic and human costs of moving and the importance of pre-existing social networks. Travelling short distances has relatively low economic costs, and within most countries (but not all) people can move without government restrictions. International migration, especially over long distances, has high up-front financial costs, and destination and/or transit countries may have legal and/or administrative barriers that discourage in-migration. Overcoming these barriers may be possible only with the help of migrant smuggling organizations that increase the financial costs and the safety risks to migrants and their families (McLeman 2019).

4. IT IS NOT EASY TO DEFINE IN LEGAL TERMS EXACTLY WHAT CONSTITUTES CRD

There are no binding mechanisms under international law requiring countries to facilitate or protect the rights of people who must move for environmental reasons. There do exist regional agreements in which countries have agreed to provide assistance to environmentally displaced people, such as the Cartagena Declaration in Latin America (UNHCR n.d.) and the Kampala Declaration made by a number African nations (African Union 2009), and in this piecemeal fashion some form of global protection might eventually emerge. In the meantime, international refugee law currently provides protection only to people fleeing across borders due to violence and persecution, and despite the best efforts of the UN High Commissioner for Refugees, the international community's efforts to assist people who merit refugee protection – particularly on the part of many wealthy nations – is insufficient. In many western countries, when migrants and refugees are discussed in public policy circles they are increasingly described as being an unwelcome phenomenon that must be controlled and curtailed (McLeman 2019). But even were there to be a sudden shift toward more enlightened views of migration on the part of governments and a greater desire to assist people that must move for climate-related reasons, we know it would be difficult to generate a satisfactory definition of what constitutes climate-related displacement because of its multicausality.

In some cases, identifying people in some formal manner as being climate-related displacees is straightforward and non-contentious. For example, if a community is burned down by a wildfire or levelled by a hurricane, most rational people would agree with designating those who must relocate as having been displaced for climate-related reasons. Slower-onset climate hazards are more problematic definitionally, but there are non-contentious examples. For example, should an occupied atoll become uninhabitable due to rising sea levels – as appears likely by the end of this century in some parts of the Indian and Pacific Oceans (Thomas et al. 2020) – most rational people would again recognize this as being due to climate change. But what if the connections between climate event and displacement outcome are more complicated? For example, what if food prices on local markets in a given country skyrocket because of weather-related crop losses, and after a time people have no choice but to move elsewhere in search of wage labor because they have no other way of feeding their families. Is this an example of CRD or do we instead label it as economic migration? A well-known example of uncertainty over causation was a discussion among scholars about whether severe drought conditions that plagued Syria between 2007 and 2009 precipitated that country's subsequent civil conflict and outpouring of refugees. Some scholars argued that the drought caused large numbers of young male workers to move into Syrian cities where they found it difficult to find work and were thus easily drawn into rival, warring political factions (Kelley et al. 2015). Other researchers found little evidence for any significant crop failures during the drought period and could identify no increase in drought-related internal migration (Eklund et al. 2022). We cannot say for sure whether the civil conflict and refugee crisis in Syria was directly caused in whole or in part by the drought, but we can say that the drought did not reduce the chances of conflict and may have amplified the risk.

5. WE KNOW WE ARE LACKING DATA

Definitional uncertainty with respect to CRD is compounded by data unavailability. Even if we had in hand a clear definition of what constitutes climate-related displacement, we would not be able to say exactly how many people there are in the world right now that would meet said definition. The data we have today is better than what was available to Myers in the 1980s but it is still coarse and piecemeal, and likely underestimates the true state of affairs. The IDMC data referred to above counts only people that move within the boundaries of their home country, and only those that move in response to events that are, in simple terms, newsworthy. IDMC does not have people on the ground investigating every possible case of CRD and directly counting the number of people involved and verifying the reasons for their movement. IDMC relies on information received through third-party reports from media, governments, humanitarian groups and non-governmental organizations. IDMC data do not count people whose displacement goes unreported or who move across international boundaries. For these reasons, IDMC data likely underreport the true number of people displaced for climate-related reasons, but we do not know by how much, and it is unlikely we will get better data from this or any other source anytime soon (but IDMC is working on it – see IDMC 2025).

6. WE KNOW THAT THE NUMBER OF PEOPLE WHO MUST MOVE FOR CLIMATE-RELATED REASONS IS LIKELY TO RISE, IRRESPECTIVE OF CLIMATE CHANGE

Floods and storms and droughts have been displacing people for millennia. Although disastrous for human livelihoods and wellbeing, such events are simply manifestations of the normal, natural variability of the earth's weather and climate. Even if human activity were having no significant effect on the Earth's climate, people would continue to be displaced by such events. The number of people on the move for climate-related reasons would vary from one year to the next, with the long-term average and trend being driven principally by the number of people living in areas exposed to such events. This means that CRD rates have the potential to grow even in the absence of climate change for reasons related to demography. A disproportionate amount of the Earth's human population currently lives in coastal areas and river valleys of low- and middle-income countries in Asia. The number of people living in these areas is growing rapidly; so, too, is the number of people living in dryland and coastal areas of Africa that are also heavily exposed to climate hazards. It is therefore safe to assume that – even without considering the changes in the frequency and severity of extreme weather that will occur because of climate change – CRD will increase globally until human population numbers in these higher risk areas plateau sometime around mid-century (UN DESA 2024). Although IDMC displacement statistics suggest an upward trend in CRD over the past decade, it may have nothing to do with climate change but may simply reflect what ought to be expected given the geographical distribution of the human population.

Known unknowns about climate-related displacement (CRD)

1. WE DO NOT KNOW IF THE CLIMATE-RELATED DISPLACEMENT WE OBSERVE TODAY IS A PRODUCT OF NATURAL CLIMATE VARIABILITY, ANTHROPOGENIC CLIMATE MODIFICATION, OR SOME COMBINATION OF BOTH

When we talk about CRD, many people – including many experts – conflate climate variability and climate change. We often do not acknowledge the important distinction between normal climate variability and the effect climate change has (and will have) on climate variability and on baseline climatic conditions. Storms, floods, droughts, wildfires and other climate-related weather events regularly displace people – they always have and probably always will – but in many regions the frequency, severity and/or geographic distribution of such events is changing and/or is expected to change because of anthropogenic modification of the climate system (Arias et al. 2021). This begs the question, how do we determine if the occurrence of a given climatic event that displaces large numbers of people, such as a hurricane or wildfire, is 'natural' or if its severity (or the fact that it occurred at all) is due to anthropogenic climate change? This question is known in the scientific community as being one of 'attribution' and is a relatively new area of research (Stott et al. 2016). Here is a simple illustration: hurricanes, typhoons and tropical cyclones form over areas of open ocean where the surface temperature is 26.5°C or higher (without going into the atmospheric physics behind this threshold, it explains why these storms form only in the tropics and not at higher latitudes). We know that anthropogenic warming is causing the oceans to trap more heat and that average sea surface temperatures are rising in many regions (Arias et al. 2021). If anthropogenic warming pushes the average sea surface temperature in a given area above the 26.5°C threshold at a time of year when the sea surface would not ordinarily be so warm, and if a hurricane should then form at that time and place, we can attribute the formation of that storm (and any damage, death, or displacement that subsequently ensues) to anthropogenic climate change. Yet, if a hurricane forms at a time of year in a location where sea surface temperatures are routinely at or above the 26.5°C threshold, we cannot attribute its causation (or its consequences) to anthropogenic climate change. However, the strength of hurricanes is positively connected to the actual temperature of the sea surface, and if that temperature is higher than might otherwise be expected, some percentage of the storm's severity (and its consequences) might be attributable to anthropogenic warming. So, for example, attribution scientists have estimated that anthropogenic warming amplified the severity of 2017's Hurricane Harvey, leading it to dump between 20% and 40% more precipitation on Houston, Texas and surrounding area than it otherwise would have (Ornes 2018).

Why is attribution important? If we do not know the extent to which anthropogenic climate change is currently affecting the formation, severity and frequency of extreme events that generate displacement, it becomes difficult to make accurate estimates of how many people are likely to be displaced in the future as the climate continues to change.

2. WE CAN PREDICT WITH CONFIDENCE THE IMPACTS OF CLIMATE CHANGE ON AVERAGE TEMPERATURES, BUT THAT USUALLY IS NOT WHAT DISPLACES PEOPLE

It is a long-established scientific fact that carbon dioxide, methane, and nitrous oxides trap heat in the atmosphere. We can measure the amount of each gas in the atmosphere in real time and we can measure the potential heat trapping effect (referred to by climate scientists as 'forcing' effect) of each of these gases. We know the approximate atmospheric concentrations of each of these gases going back hundreds of thousands of years and can demonstrate conclusively that human activity – the burning of fossil fuels, cement and steel production, and clearance of forest cover – has led to a rapid accumulation of greenhouse gases in the atmosphere over the last two centuries (Arias et al. 2021). We also know that these changes in the atmosphere have caused average global temperatures to rise by nearly 1.2°C over the past 150 years, with the year 2024 being approximately 1.6°C warmer than the pre-industrial average (Copernicus 2025). In short, we know beyond any doubt what human activity has done to change the atmosphere, and we can use computer models to estimate with some degree of confidence how much additional heat will be trapped in the atmosphere in coming decades.

However, changes in average temperatures do not typically cause displacement – at least, not yet. There is some concern that by the end of this century, average summer nighttime temperatures may become so hot in some regions of the world they will exceed the threshold for human survival out of doors (Vanos et al. 2023). Whether that would in turn lead to large scale population movements would depend heavily on access to indoor cooling and on institutional measures to assist those most vulnerable. But what we do know from current experience is that extreme events certainly cause displacement and are far more likely to continue doing so than any incremental changes in average conditions. Unfortunately, the models scientists currently use to predict future anthropogenic climate change and its impacts are very poor at predicting, with any accuracy, changes that may emerge in precipitation, winds, or storm activity. We can say in general terms that as average temperatures rise, we can expect more frequent and/or more extreme storm activity, but we cannot really say where or when this might happen except in broad geographical terms (e.g. the Mediterranean region will become hotter and drier, East Africa might experience more precipitation during the rainy season, etc. (Arias et al. 2021)). We can expect climate modeling technology to improve with each passing year, allowing for more precise predictions of how those aspects of climate that have the greatest impacts on migration and displacement will evolve in coming decades and where specifically they are most likely to occur and how often; in the meantime, we will have to live with a considerable degree of uncertainty.

3. WE DO NOT KNOW IF PEOPLE WILL ACTUALLY DO ANYTHING TO REDUCE GREENHOUSE GAS EMISSIONS

This is perhaps the most important uncertainty of all. The scientific community has made it clear that any progression in global warming beyond a 1.5°C increase over pre-industrial temperatures is dangerous, and every fraction of a degree of additional warming elevates the risks to human wellbeing (IPCC 2018). Under the 2015 Paris Agreement, the international community has pledged to take collective actions to ensure that average temperatures do not exceed 2°C of warming and ideally not more than 1.5°C. But our collective actions are falling short and we are currently on a path to nearly 3°C warming by the end of this century (United Nations Environment Programme 2024). If we do not divert from this path, the frequency and severity of extreme weather events will be considerably higher than today, and sea levels will on average be more than a half-meter higher by the end of this century – changes that would almost certainly generate a significant increase in the number of people displaced worldwide. But simply assuming that recent rates of global emissions will continue indefinitely into the future is unsatisfactory. It may well be that uptake of alternative energy technologies will accelerate and displace fossil fuel use rapidly, thereby bringing future emissions levels down rapidly. Conversely, rapid fossil fuel-driven economic expansion in low- and middle-income countries (eagerly facilitated by fossil-fuel exporting countries) may push emissions even higher for decades to come. We cannot be sure which emissions pathway we will be on twenty, thirty or fifty years from now, and so we must resign ourselves to making predictions about potential future exposure to climate hazards using a range of emissions scenarios, the ones currently in use by climate scientists being known as the Representative Concentration Pathways (RCPs) (van Vuuren et al. 2011).

4. WE DO NOT KNOW IF POOR COUNTRIES AND POOR PEOPLE WILL CONTINUE TO BE POOR

One thing we do know is that the likelihood of people being displaced by climate hazards is moderated by improvements in the socio-economic well-being of the people exposed and the institutional capacity of their governments (Cissé et al. 2022). Put more simply, wealthier people in wealthier communities and countries are less likely to be displaced by extreme events and more likely to recover quickly if they are. We know from IDMC statistics that most CRD occurs in low- and middle-income countries in Asia, typically because of floods and storms, with large numbers of displacements also occurring in Africa and Latin America and the Caribbean in some years depending on storm and drought activity. What if countries that are currently low- and middle-income become high-income countries in coming decades? The World Bank's *Groundswell Report*, which sought to project mid-century population movements in low- and middle-income countries due to climate change reached a wildly divergent range of estimates (between 9 million and 216 million people) depending upon future emissions scenarios and future economic development scenarios (Clement et al. 2021). If the international community were to make renewed efforts to achieve the UN Sustainable Development Goals (SDGs) and if poor people living in poor countries become less poor, their ability to cope with and adapt to climate risks would improve, and their risks of displacement would fall. Conversely, if we make no meaningful progress on the SDGs in coming decades, the number of poor and vulnerable people will grow and so, too, will the number of people displaced by climate hazards. Again, the best we can do is model future outcomes using a range of socio-economic scenarios, the ones currently in use by researchers known as the Shared Socio-economic Pathways (SSPs) (Riahi et al. 2017).

5. WE DO NOT KNOW IF CURRENT ATTITUDES TOWARD MIGRATION WILL PERSIST

In recent years, governments of high-income countries have come to view international migration as a crisis – something to be controlled, constrained, and prevented (McLeman 2019). Governments that are quick to proclaim how much they value human rights and quick to accuse other countries of failing to do so (e.g., European Union, Australia, USA) are at the same time actively implementing strict border controls to prevent the arrival of people seeking asylum from violence and conflicts. This is even though the UN Refugee Convention – which all of these countries have signed – explicitly states people have the legal right to make an asylum claim and have it adjudicated. Most countries are happy to facilitate the immigration of health care professionals and skilled workers, but unskilled workers are less welcome (but may be tolerated so long as they work in unpleasant jobs that are hard to fill) and asylum seekers are often not welcome at all. Will these anti-immigrant sentiments persist into the future? Will wealthy destination countries double down on efforts to keep people out? Will climate-displaced people in low-income countries be prevented from migrating to wealthier countries? Recent experiences at the US border and on the Mediterranean suggest that international migration out of low- and middle-income countries would not be curtailed entirely but would instead be channeled into clandestine migration facilitated by organized criminals (Triandafyllidou et al. 2023). On the other hand, as populations age in high-income countries and labor becomes scarcer, perhaps immigration will be viewed more favorably. A recent study for the Migration Policy Institute in which I used three very coarse scenarios for future international migration policies (easier to migrate, more difficult to migrate, status quo) combined with RCP and SSP scenarios predicted very different outcomes in terms of the direction of future climate-related migration and displacement (McLeman 2020), suggesting it would be useful to develop standardized scenarios for future migration policies and politics.

Deep uncertainty, part I: What if we are wrong about what we think we know?

Deep uncertainty can take two forms: (1) things we believe to be true based on existing evidence, but we are actually wrong about, and (2) things that are happening or might happen but we are unaware of their existence (Rumsfeld's 'unknown unknowns'). Science offers many examples of these, a relevant one coming from the early days of scientific study of the effects of ozone-depleting compounds on the stratosphere. Starting in the late 1950s, scientists began taking regular measurements of stratospheric ozone concentrations over Antarctica. These concentrations decreased rapidly in the mid-1970s and a 'hole' in the stratospheric ozone layer started to emerge, but it went unnoticed because (1) scientists were not expecting a rapid decrease to happen and therefore were not actively watching for it and (2) no one had bothered to systematically analyze historical ozone measurement records until the mid-1980s (UKRI 2021). Once the problem was recognized, the international community sprang into action, and an accord aimed at reducing the production of ozone-depleting substances was successfully created. We might therefore now ask, are there things happening right now to the climate that we are unaware of or not looking for? Are we failing to analyze or interpret correctly the data we do have?

Consider sea level rise. In the decade 2010-2020 sea levels rose on average globally by about 5mm per year, but in prior decades the rate of increase was much lower (Arias et al. 2021). Was the last decade simply an anomaly, and will the rate of sea level rise return to its previous level, or is there an acceleration underway? IPCC reports suggest that we are most likely on a trajectory to an average increase in sea levels of 50 to 60cm by the end of this century which, if correct, would seemingly provide plenty of time for coastal communities to implement adaptive measures. However, a recent study by Vernimmen and Hooijer (2023) suggests we may be grossly underestimating the rate at which the early stages of sea level rise will damage coastal settlements, and projects a worst-case scenario starting as early as thirty years from now. What if this latter study is correct and IPCC reports are lulling us into misplaced inaction? The consequences for coastal cities and settlements would be genuinely catastrophic.

In a similar vein, scientists are aware that long-term changes in the climate could affect ocean currents that redistribute heat from the tropics to temperate regions, such as the Atlantic Meridional Ocean Circulation (AMOC) that draws warm surface water from the tropics toward Europe and moderates average air temperatures in Europe. Most climate models predict that significant changes to AMOC will not happen for centuries, even in a rapid warming climate scenario (Arias et al. 2021). But a recent study by Ditlevsen and Ditlevsen (2023) warns we are grossly underestimating the risk, and that the AMOC may reach a tipping point as early as the 2050s. Again, the consequences could be catastrophic if the majority view is incorrect.

For both sea level rise and AMOC, if we are underestimating the probability and timing of the risks, not only are the risks of large-scale population displacements much more likely and imminent than we currently anticipate, but we are also leaving ourselves with little time to think rationally about how we might manage, what resources would need to be mobilized and where they would come from. There are other risks that we might also be underestimating, such as the impacts of climate change on global food and water supplies that, should they occur more rapidly or on a greater scale than we presently anticipate, would also lead to far greater CRD than we might otherwise expect. Further, there may be critical thresholds in terms of people's ability to cope with and adapt to climate hazards that, once passed, cause CRD to increase rapidly (Bardsley & Hugo 2010; McLeman 2018). The problem with thresholds is that they are easy to identify in hindsight but difficult to see in advance. Worse, there may not even be a single threshold to watch out for, but instead a near-infinite number of potential causal factors, none of which on its own can trigger large-scale displacement events but that in particular combinations might progressively lead to worst-case scenarios rapidly coming true.

At the same time, we should not expect that all future known unknowns and unknown unknowns will be harmful to human wellbeing or heighten the risk of displacements. Perhaps we are wildly underestimating the rapidity with which alternative energy generating technologies and energy storage technologies (including ones still in development) will be implemented and replace fossil fuels. Should this happen, not only would CRD risks decline due to the worst potential impacts of climate change being avoided, but such technological innovations would also reduce poverty and lack of access to cheap energy in low- and middle-income countries, spur progress toward achieving the SDGs, and thereby further reduce future CRD risks. In other words, we could be closer than we know to a synergistic transition to a very promising future. Such synergy could be further enhanced by rapid improvements in political relationships and cooperation between and within countries. Given the current conflicts in Ukraine, Sudan and the Middle East, the growing corruption and public indebtedness in many countries, and the inherently self-interested political conduct of many nation states, it may seem naïve to hope for genuine global political, social and economic cooperation. However, there are examples where the international community has shown itself capable of working together constructively – such as the creation of the United Nations and its many organizations, the Vienna Convention on Ozone Depleting Substances, and the continued annual conferences of countries party to the UN Framework Convention on Climate Change – and we need to keep building upon these even as we rue daily examples of conflict, corruption, and chaotic behavior by elected officials. A cooperative future is not in itself an unknown possibility, but the pathway(s) to achieving it are less obvious.

Deep uncertainty, Part II: How do we cope with unknown unknowns?

The notion that climate change may have some nasty surprises in store for us is not new; climate scientist Michael Glantz and colleagues (1998) were writing about 'climate surprises' for the US Department of Energy almost thirty years ago. Notably, Glantz was earlier known for researching the impacts of climate change through use of 'historical analogues': carefully selected examples from the past that, when analyzed systematically, yield useful insights for the future (Glantz 1991). Glantz later recognized there are limits to what we can anticipate on the basis of past experience about how the climate will behave in coming decades when there is no direct comparability between the underlying composition of the atmosphere in the past versus the future.

Our existing toolkit is of limited assistance to us when trying to imagine what surprises or unknown unknowns might be lurking in terms of future CRD. Systematically designed scenarios of the future are among our few tools and are often a product of groupthink in which all unknowns are presumed to be known or knowable (I know this from past experience). They often discount the existence of unknowable or unforeseeable factors that make future outcomes appear to be random. A common practice in scenario building is to take a group of knowledgeable people and ask them what they think the future will hold, and the responses that are repeated most often are selected to construct the scenario. If, for example, 10 experts are consulted and 8 say the future will be X, one says Y and one says Z, scenario X will be taken as the most likely, and Y and Z might be seen as low-probability outcomes or discarded entirely. But what if X is entirely wrong? What if Y or Z is the correct guess about the future? Or what if none are correct because they are all based on faulty assumptions or incomplete data? Once scenarios have been constructed, they may then be tested in hindcast modeling exercises, compared qualitatively against contemporary or historical cases, or perhaps evaluated subjectively by a selection of non-participating experts through Delphi or some other method (the actual process of development and consultation may be more complicated). It means that from the outset, scenarios are educated guesses based on past and current data and experiences, and have strong potential to be wrong. Exactly how wrong can only be revealed at some time in the future. A good example of this was mentioned earlier; Ehrlich's *Population Bomb* (1968) and the Club of Rome's *Limits to Growth* (1972) predicted that socio-economic collapse and chaos due to exhausted food systems and resource supplies would occur sometime in the 1980s or 1990s. Neither foresaw that massive increases in global yields of staple food crops that began in the 1960s would continue in future decades, or that birth rates in populous countries such as China and Indonesia would fall, among other incorrect assumptions and oversights.

Scenarios, including those currently used by climate scientists, often exclude low-probability/high-impact events, and cannot capture events for which data are missing that would otherwise allow advance recognition. Taleb (2007) describes these latter cases as 'black swan' situations (based on an example that European swan species are all white in color, but once Australia was 'discovered' by Europeans they learned that swans could also be black). Further, when crafting scenarios we often tend to exclude what we consider to be 'random' events that have no obvious causation. Yet what we think is 'random' might actually be events for which there is a measurable predictability, but we are blind given current information.

A related challenge is that humans tend to have difficulty thinking beyond the timeframes of their own lifetime, but the return rates of many ecological events are longer than a single human lifetime. For example, palaeoclimatological studies have shown that on the North American Great Plains, the 20th century had unusually high rates of precipitation, and that in previous centuries it was not uncommon for droughts to last for decades (McLeman et al. 2014). Even the legendary Dust Bowl years of the 1930s, when hundreds of thousands of people were displaced from the region, were not especially dry in the longer historical context. Given this information, one would think today's residents, land managers and governments would be actively preparing for the next inevitable 'mega-drought' but they are not, because the chances are slim of one emerging within the 5- to 10-year time horizons that for many people and government agencies constitute 'long term' planning.

If we ignore potential 'black swans' and do not plan for them, that is a problem. But it is also a problem if we act upon scenarios and they turn out to be badly wrong. This is especially true in the case of climate change; if the RCPs and/or SSPs are insufficiently pessimistic about the future, actions proposed under the Paris Agreement are woefully inadequate, are moving much too slowly, and setting us up for genuine catastrophe later this century. Conversely, if they are overly pessimistic, resources currently being dedicated to mitigation and adaptation might be better channeled to addressing other societal challenges. We might also be blind to potential good 'black swans' – unforeseen events that turn out to be wildly beneficial, such as was experienced by anyone who in December 1980 bought a single share in Apple Computer stock for the then high price of US$22 and held onto it (that share would be worth over US$20,000 today). Similarly, if one had purchased one of the first Apple I computers and kept it, it might today be sold for hundreds of thousands of dollars (Christie's 2015). Suggestions I made earlier about emerging non-carbon energy technologies and pathways that lead to global political cooperation are also examples of potentially favorable 'black swans' and we should be doing everything in our power to figure out how to make them happen.

Lessons from gaming about how to tackle unknown unknowns

Taleb's advice with respect to 'black swans' is to not try and anticipate them; rather, he recommends taking precautionary measures to minimize exposure to unexpected bad surprises and maximize exposure to unexpectedly good surprises (Taleb 2007). His examples come primarily from his own experience in the world of private investment, where he cautions that it is not possible to predict when the next stock market crash will occur or guess which new start-up company will be the next Apple versus those destined to join the larger number of companies that sooner or later fail. His strategy is to keep the bulk of his wealth in low-risk, slow-growing assets like US treasury bills but invest small amounts of money in lots of start-up companies in the hope one of them will make it big. In this way he avoids exposure to inevitable stock market downturns and cashes in on the next Apple (he is a wealthy individual as a result of this strategy). Our ability to predict and prepare for future CRD will likely have potentially far greater implications for human wellbeing than knowing how to gain from unpredictable stock markets. CRD is even more unpredictable than stock markets, being a function of such complex interactions of global-scale ecological and human systems, for which scientists still have a poor working knowledge. How might we come up with a strategy to tackle unknown unknowns in the context of CRD?

Matt Q is a Dungeons & Dragons (D&D) game master, who has for many years created elaborate online games that are played over months or years. I asked him for the purpose of researching this article if there was ever a game he created where an unexpected outcome caught him completely by surprise (I didn't use the terms 'black swan' or 'unknown unknowns' but that is what I meant). He explained that a challenge with D&D is there are many improbable but mathematically possible outcomes embedded in any game that even the best game master cannot reasonably anticipate in advance. He described a game he once crafted where one of the players unexpectedly found himself in the presence of an enemy. The chance of the encounter was not large; it happened when the player rolled the number 1 on a 20-sided die in a particular episode of the game. The ferocity of the enemy's attack was determined by rolling the 20-sided die once again, which landed on the number 20 – the most ferocious of all possible attacks. The player attempted to flee rather than fight – the correct response given the parameters of the game – but the player again rolled a 1 on the 20-sided die, the worst possible score in that situation, meaning he could not escape. His final roll of the 20-sided die was again a 1, which meant the immediate death of his character and expulsion from the game he had been playing for months with the same group of players (harming his future interactions with them in real life). Matt explained that in previous games he had never encountered that particular sequence of rolls on a 20-sided die, and it was so mathematically improbable he had not considered what the outcome of such a sequence could be for players. In the language of the present article, it was a potentially knowable unknown for which Matt's past experience had not prepared him.

The player whose character died contributed to his own demise: his character had wandered so far from other players they could not come to his assistance (D&D players are typically cooperative and will help one another whenever possible). Also, he had not expected such a terrible outcome could occur in a game Matt designed ('how could he do this to me?!'). Matt is today more conscious of low-probability/high-impact events and will now build into his games some form of 'bad luck protection' for players, soften the potential severity of adverse events, or include modifier rules that can be initiated spontaneously to prevent catastrophic outcomes should an unlikely sequence of rolls of the die occur. Matt Q's advice for D&D players is to accept and expect there will be unexpected risks in each game that cannot be avoided, and in the face of this uncertainty the only thing that can be done proactively is to be ready to react quickly if/when they happen (which sounds somewhat like Taleb's strategy for minimizing risks and maximizing profits on the stock market).

In case they are not already obvious, lessons we can take from the D&D world and apply to the challenge of CRD in the real world include:

- working cooperatively and being available to assist others in a time of need is essential to avoiding and recovering from catastrophic events,
- we must strive to build into our socio-economic systems mechanisms that can soften the blow of events that can lead to displacement,
- and we must accept we will not be able to foresee *every* crisis, but we can strive to build the ability to respond rapidly to any crisis.

As researchers interested in CRD, the work we do can help remind decision makers and the wider public of these lessons. In conducting our research, we might also emulate D&D game masters like Matt Q, who aim to be wildly imaginative and creative but at the same time consider all possibilities, no matter how remote, and their consequences.

Lessons from time travel

If a creator of worlds (albeit fantasy ones) cannot foresee all future events that might occur within them, what hope is there for us mere mortal CRD researchers trying to identify the events a climate-disrupted future might bring? Another way of thinking about unknown unknowns is a thought exercise in which we imagine we have a time machine (I use this often in my first-year undergraduate classes). Let us use this time machine to travel to the year 1800 and ask the most knowledgeable people of the day to describe what they think the world would be like in the year 2025: what technologies we would be using, how the economy would function, what the climate would be like, how global politics would operate, what degree of mobility people would have, and so forth. That is, ask them to reflect upon the same topics this article has been considering. How close would the experts of 1800 come to being correct? Would they be able to predict the internet, cryptocurrency, social media, air travel, a planet of 8 billion people? Probably not, because many of the key pre-cursor technologies needed to enable the world of 2025 had not yet been invented (e.g., electrical generation, internal combustion engines, aircraft, telephones, computers, satellites, mechanized food production, genetic modification…). Things that are common in 2025 were unknown unknowns in the year 1800. Now let's travel ahead to the year 1900 and repeat the exercise. Many more of the necessary precursors for 2025 society are now in place, many others might be potentially anticipated (i.e. known unknowns), with fewer things being unknown unknowns. While there, we might stop to chat with E.G. Ravenstein, who had a decade earlier published his Laws of Migration (1889). He would probably feel a need to revisit some of his 'laws' (or perhaps relabel them as 'currently observed tendencies in migration') once we told him that in the 21st century hundreds of thousands of people each year migrate from the Philippines, Pakistan, China and India to Canada, that women in many countries and in particular sectors make up a large portion of labor migrants (see e.g., Hillmann et al. 2022), and that we were starting to worry about large-scale displacements due to anthropogenic modification of the climate.

The time machine thought exercise reminds us that, in terms of anticipating what CRD might be like in the year 2050 (or 2075 or 2100), we may today be in the same position as experts in the years 1800 or 1900: the information necessary to accurately foresee what is yet to come is beyond our ken at this moment, but our knowledge will improve. Our aims as researchers should therefore be twofold: to work continuously to generate new knowledge of human-climate interactions that lead to displacement without worrying about whether it will provide us all the answers (i.e. that curiosity-based knowledge is important); and be open-eyed and ready to recognize those 'eureka' moments whenever we learn something that helps illuminate an unknown unknowns lurking in the dark.

Concluding thoughts: Moving ahead in deep uncertainty

Since time machines do not exist except as thought experiments, we have no practical way of knowing what exactly the future will hold. That is ok. A key lesson from the time machine thought experiment is that, with the passage of time and progression of scholarly inquiry, many unknown unknowns will become known unknowns and then, hopefully, known knowns for which we can assemble empirical data to make reliable projections of what is likely to happen and what we can do in response. And this progression may occur quite rapidly (as an example, think of how our ability to conduct scholarly research has improved with the advent of the internet). But in the meantime, how should we as researchers approach the subject of CRD under conditions of deep uncertainty?

A first step is to avoid getting hung up on disciplinary norms and practices. The more perspectives and skills we can bring to bear on the challenge, the better. Having trained academically as a geographer and environmental scientist, I tend to place methods into three non-mutually exclusive categories and encourage a mixed practice of all: qualitative approaches, quantitative approaches, and geomatic-based approaches that use Geographical Information Systems (GIS) to analyze data and then provide geo-visualizations of the results. Qualitative research has generated tremendously important insights into the context-specific causality of CRD, highlighting the interconnectedness of climatic and non-climatic processes in shaping vulnerability to CRD and the outcomes that occur. More such research is needed, for we have barely scratched the surface. We also need more qualitative research into how to minimize CRD or avoid it altogether. In its 2022 Working Group II report, the IPCC dedicated an entire chapter – and sections of other chapters – to identifying what it refers to as 'climate-resilient development pathways'. These consist of political, social, economic and technological options that might mitigate greenhouse gas emissions and improve people's capacity to adapt to climate change as part of wider goals of fostering sustainable development (Schipper et al. 2022). Continued investment in qualitative research will help us identify development pathways that minimize the occurrence of CRD related to extreme events, accelerate the recovery time of populations that experience it, and build greater adaptive capacity for the longer-term environmental changes climate change will bring. How do we go about identifying these min-max pathways for dealing with CRD through qualitative research? One way would be by identifying and studying more examples of communities that have experienced climate hazards but avoided high levels of displacement, whose members have quickly recovered (or improved upon) their pre-disaster standard of living, and where planning measures are being taken to reduce future risks (see e.g., Handayani et al., in this issue). Such examples do exist (scholars in the fields of natural hazards and political ecology tend to be good at spotting them); let us make additional efforts to identify success stories, dive into them as deeply as possible to identify takeaway lessons for others, and compare and contrast them. It may be that the solutions pathways for minimizing CRD and maximizing recovery from CRD events are already being implemented somewhere and we need to make them more widely known.

For quantitative researchers in any field, a limit until recently has been the ability to acquire, process and analyze large amounts of data. The advent of artificial intelligence (AI) and machine learning allows for the acquisition and analysis of huge amounts of climatic, demographic and socio-economic data at a variety of spatial scales, which can be explored and assessed to identify causal variables and interactions among them that might have heretofore gone unnoticed in CRD research (McLeman et al. 2022). By shedding additional light on the complexities of past and present CRD, we will be in a better position to identify with greater accuracy potential CRD risks in the short- and medium-term future (again with the caveat that what we learn from current experience may become decreasingly relevant the more the composition of the atmosphere changes). Conducting such research within a geomatics-based environment is becoming increasingly easier as AI and machine learning-capable software packages are combined with GIS software, and this in turn allows new opportunities for researchers to create geo-visualization tools that allow end users – decisionmakers, planners, and the wider public – to view known CRD examples and experiment with their own 'what-if' explorations that play with any number of combinations of future climatic, economic, social, and political trends. We are not all the way there yet, but I suspect such tools will be widely available within a decade or so (see Iazzolino, in this issue, for further reflections).

In conclusion, the consequences of unprecedented modification of the atmosphere currently taking place include an unknown number of unknown unknowns. As researchers and as participants in society, we can help by using the tools and data at our disposal as creatively and effectively as possible, studying the less likely outcomes as well as the most likely ones, providing evidence for the role mobility plays in climate adaptation, and using our research to advocate for greater cooperation in pursuing climate resilient development pathways.

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