The dangers of disaster-driven responses to climate change

Low-probability, high-consequence climate change events are likely to trigger management responses that are based on the demand for immediate action from those affected. However, these responses may be inefficient and even maladaptive in the long term.

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Climate change has impacted physical, biological and human systems, and many of its effects are expected to increase in severity and magnitude in coming decades[1]. Some changes will happen gradually, such as sea-level rise and shifts in species ranges. Other impacts, such as floods, fires and disease outbreaks, are acute, low-probability events with widespread consequences. In light of recent social science research on the role of salience in decision-making, we argue that although the risk of episodic high-impact events can motivate planned adaptation, it is the occurrence of events that often leads to action.

Salience theory predicts that people experiencing low-probability, high-consequence events give those events disproportionate weight in subsequent decision-making because their attention is drawn to them as standing out from the norm[2]. Because governments rely on public perceptions and input to allocate public goods that are intended to modify hazards, events that raise the salience of risk will make people and governments more likely to pay attention to that risk, act on that risk or demand action from others — regardless of whether such actions actually reduce risk. While salience-driven decision-making can facilitate action that reduces risk, it can also lead individuals and governments to respond in ways that are inefficient or even maladaptive — such that the allocation of resources could more effectively address future risks or the responses may actually increase future risks.

Here we describe examples of how salience provides a behavioural link between episodic climate impacts with substantial societal and ecological costs (wildfire, floods, disease outbreaks) and observed responses that can be inefficient or maladaptive (Table 1). Ignoring this behavioural link inhibits successful strategies for climate change adaptation planning.

Wildfire and salience

The threat of wildfire in the western United States has increased in recent decades, owing to factors including climate change[2], the expansion of the wildland–urban interface (WUI) and the history of wildfire and forest management[3]. Salient wildfire events have led to human responses with both inefficient and maladaptive consequences for natural systems and future wildfire. For instance, wildfires close to the WUI stimulate subsequent investment in fuel reduction projects, such as mechanical thinning and prescribed fire. Specifically, land close to WUI communities that experience a fire is 50–75% more likely to receive fuel management in the year the fire occurs than similar land that did not experience a fire[4]. This salience-driven fuel management allocation may be inefficient because preoccupation with the short-term, visible action of reducing fuel may overshadow crucial steps (such as changes in land-use planning) that can be taken to reduce human vulnerabilities in the longer term[5]. Fuel treatments near recent fires may also displace fuel treatments in other locations that would result in more effective modification of subsequent fire hazard.

More generally, the US Forest Service policy of aggressive suppression throughout much of the twentieth century was driven in part by the massive and highly salient wildfires of 1910 in the western United States. This wildfire suppression was largely successful, but produced unintended consequences. Fire exclusion made many forests more dense and flammable, causing subsequent fires in hotter and drier climates to be even more hazardous[6].

Flooding and salience

Climate change is expected to accelerate the hydrologic cycle, increasing the frequency, magnitude and severity of floods[7]. Salient floods are a catalyst for human modification to the landscape, including engineering of channels, dams and levees intended to reduce the magnitude of subsequent flooding[8]. However, these responses can lead to increased damages from subsequent flooding events by altering the physical features of floods, including their spatial extent, duration and depth[9]. For instance, the 1993 flood of the Mississippi, resulting in more than US$10 billion in damages, was impacted in complex ways by flood control structures implemented in response to earlier floods. Peak discharges in some locations were reduced by upstream reservoirs, but in many sites, flood levels were increased by levees and other channel engineering efforts that prevented water storage in floodplains[10]. In another example, the failure of levees combined with backwater effects associated with dams contributed to the extent of the 2010 floods in Pakistan that resulted in more than 20,000 fatalities[11].

At the individual level, rather than making long-term changes — such as moving out of the floodplain or making housing less vulnerable to flooding — people often take short-term actions. For example, flood insurance purchases are highly correlated with floods in the previous year[12] and housing prices decrease immediately after a flood[13]. Yet these changes in behaviour are short-lived[14].

Infectious disease and salience

Outbreaks of zoonotic and vector-borne diseases tend to be salient because of high pathogen virulence or perceived risk of adverse health outcomes (for instance, severe neurological disease caused by West Nile virus or microcephaly caused by Zika virus). The rate of emergence of such diseases has increased in recent decades[15], with temperature-driven range shifts and/or expansions expected for the types of species that act as vectors[16]. Elevated salience can result in suppression of mosquito populations via application of insecticides to breeding habitats or aerial spraying to kill adult mosquitoes[17], which reduces pathogen

Table 1 | Inefficient and maladaptive salient responses to three hazards linked to climate change

Hazard	Inefficient responses		Maladaptive responses
	Short-term efforts	Not distributed according to risk	
Wildfire	Manage fuels only in the period immediately after a fire	Reduce fuels where there has just been a fire, an area that may have lower risk relative to an area that has not had a fire	Suppress fires resulting in fuel build-up, which leads to more severe fires
Flooding	Stockpile sandbags rather than move from the floodplain	Repair levees near the flooded area even if other regions are in greater disrepair	Build levees that increase the effect of subsequent floods when overtopped
Infectious diseases	Spray insecticides rather than drain areas of standing water	Apply control measures in areas with rare emerging pathogens rather than areas with a higher burden of endemic pathogens	Apply spray and treatments that cause resistance and worsen subsequent outbreaks

transmission to humans and probably reduces transmission between mosquitoes and other host species, such as passerine bird hosts for West Nile virus.

However, alternative strategies, including removal of mosquito breeding habitat by reducing standing water on the landscape[18], improving housing quality to reduce exposure to mosquitoes[19] or limiting contact with vectors through behavioural changes or land-use planning[20] are probably more effective long-term changes that address the underlying factors elevating the risk of disease outbreaks.

Salience-driven responses to disease outbreaks can exacerbate future outbreaks. Continued use of insecticides for mosquito control is a short-term response to an episodic problem that can lead to the development of insecticide resistance in mosquito populations[21]. For example, in Boa Vista, Brazil, an aggressive campaign of insecticide treatment following identification of a single patient infected with the DENV-4 serotype of the dengue virus, long thought to be absent from Brazil, led to the rapid development of insecticide resistance throughout the region[21].

Adaption given salience

As low-probability, high-consequence hazards become more frequent and intense or change in distribution with climate change, accounting for the potential of salience to lead to human responses that have both limited effectiveness in reducing risk and unintended consequences on subsequent risks will be important for understanding how human systems are likely to evolve Much of the literature on planned adaptation to climate change focuses on organized planning that endeavours to meet multiple stakeholder goals over medium-term time horizons[22]. However, these organized planning initiatives and recommendations for more effective and equitable adaptation do not take into account the reality of salience-driven responses that may shape when and where adaptation occurs.

Salience is likely to shape climate change impacts in ways that have not been widely explored by the regional and global Earth system modelling communities[23]. Despite the fact that salience-driven management can increase the intensity of subsequent events, predictions of the impact of climate change on natural systems often do not account for human actions — or they assume that these actions will effectively reduce intensity of fire, floods and disease. Improved impact assessment and modelling would include the role of salience and how it motivates human modifications to the natural environment that may produce unintended, but significant, consequences.

Harnessing salience may provide opportunities to focus attention and resources on the amelioration of human impacts on the natural system and on reducing human vulnerability to subsequent events. For example, immediately after a fire, when citizen attention is high, local officials might focus not on fuel treatments but on retrofitting of houses or zoning that reduces encroachment into the WUI, both of which would reduce vulnerability over the longer term[5,6]. Or they might use a salient fire as the focus of an extended information campaign that emphasizes the importance of continued yearly maintenance of defensible space around homes. Salience may even offer opportunities for promoting GHG mitigation if policymakers can recognize and exploit the moment of increased salience to motivate climate change mitigation[3,24]. The issue is not whether salience is the preferred mechanism for adaptation, but rather what mechanism is preferred given that salience-driven responses occur. Taking salience seriously, and even utilizing its power in shaping human responses to hazards, can advance our understanding and prediction of the consequences of climate change and improve the likelihood of successful adaptation. ❐

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Sea-level commitment as a gauge for climate policy

A well-defined relationship between global mean sea-level rise and cumulative carbon emissions can be used to inform policy about emission limits to prevent dangerous and essentially permanent anthropogenic interference with the climate system.

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It is now clear that cumulative emissions of CO_2 control the magnitude of long-term warming[1,2], while the rate of warming is modulated by the emissions pathway[3], facilitating the identification of emissions quotas that would limit global warming to a temperature target mandated by climate policy[4]. This framework forms the cornerstone of the Paris Agreement adopted in 2015 under the United Nations Framework Convention on Climate Change (UNFCCC), which aims to hold "the increase in the global average temperature to well below 2 °C above pre-industrial levels and [to pursue] efforts to limit the temperature increase to 1.5 °C" by providing the means to both quantify the allowable budget of remaining emissions required to achieve the treaty goals[4] and assess the implications of emissions-reduction pledges made by countries[5].

Although temperature has been used as the main indicator to gauge the long-standing UNFCCC goal of avoiding "dangerous anthropogenic interference with the climate system"[6], we argue that global mean sea-level rise (GMSLR) would be a useful additional measure for setting emissions quotas to achieve this objective[7]. The enormous socio-economic and ecological impacts of GMSLR and sea-level extremes during the twenty-first century are well known[8]. Coastal submergence from SLR and the corresponding increase in the frequency and intensity of sea-level extremes will irreversibly affect the distribution of a large fraction of the human population[8–10]. Forty per cent of the global population (nearly three billion people) reside within 100 km of the coast. Much of that population is concentrated in megacities and on fertile low-lying floodplains, river deltas and islands — areas that are at high risk of impacts from GMSLR. The United States reflects this tendency, with roughly 50% of the population in coastal counties[9]. Increasing population density along coastal zones in the coming decades to centuries will exacerbate these problems[11].

In the absence of effective mitigation, GMSLR will accelerate over the coming centuries, and will continue for millennia[10,12]. Persistent long-term SLR will increase the frequency and amplitude of sea-level extremes. Because extreme events occur on such short timescales, they will be among the most disruptive mechanisms of coastal inundation, and their effects are already manifesting themselves through increased coastal flooding[13,14]. This increase in sea-level extremes will be an early driver of sudden, large-scale, permanent displacement and migration that expands the socio-economic impacts of SLR beyond the coastal zone to locations where migrants will require jobs, housing, healthcare, schools and other services[9]. With no adaptation, economic losses in large coastal cities due to coastal flooding are estimated to grow from US$6 billion annually in 2005 Common Era (CE) to US$1 trillion by 2050 CE[15]. These losses can be reduced to US$60–63 billion through construction of coastal defenses[15], but such well-intended, short-term efforts neglect the long-term horizon of SLR, and thus may increase long-term risks by encouraging coastal development — effectively committing future resources to further defensive measures as sea level continues to rise.

Using cumulative carbon emissions to project GMSLR offers the same advantages as using temperature, as this approach combines the uncertainties associated with climate sensitivity and carbon cycle feedbacks[2]. Like temperature, SLR will occur across the planet unevenly, with departures of >20% from GMSLR possible[16]. The physics behind these departures involves the gravitational, deformational and rotational effects of the loss of land ice, and is sufficiently well known that if the land-ice contributions to GMSLR are well constrained, much of the regional rise can be predicted with reasonable accuracy[17]. However, the response time of GMSLR to climate change due to CO_2 emissions is much longer than that of temperature. At least 90% of peak warming in response to an emission is realized in less than a decade[18], so that transient and peak-warming responses to cumulative emissions are similar. In contrast, the sea-level response time ranges from 10^1–10^2 yr for glacier contributions to 10^3 yr for contributions from deep-ocean warming and ice-sheet melting (if triggered, ice-sheet dynamics may shorten this response). GMSLR from these combined contributions thus continues for many millennia[10]. For this reason, any proportionality between GMLSR and cumulative emissions is transient, and that relationship will evolve over long timescales.