Natural Hazards, Climate Change, and Adaptation: Persistent Questions and Answers

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Abstract
In research on risk and hazard, three central questions seem to persist: What should people and societies worry about? Why do people live and work in areas subject to repeated hazards? How is it that they survive and even prosper in such areas? Les Heathcote and I were part of an early effort to address these questions globally across the range of natural hazards. working together on a study that contrasted the agricultural drought hazard in Australia with that of Tanzania. From our comparison and other national studies, we learned that developing countries had much greater hazard deaths rates and industrialized countries had much larger economic losses. Adding in the costs of adaptation effort to prevent these losses gave us an overall social cost, and as the percentage of per capita GNP current at the time, the burden on the developing countries was much greater than that of the industrialized countries.

Now forty years later, human-induced climate change that we did not consider in our original study, will almost surely bring more drought to some areas, more floods to others, and possibly more and greater cyclones. In this paper I examine global trends and causes of extreme climatological, weather, and disaster events, since our original study. These events are growing and have multiple causes of growing population, and economic wealth, as well as weather and climate. I then consider trends in adaptation especially as it is addressed to climate change. For a conclusion, I briefly reconsider the persistent questions.

In looking back over my half century of research on risk and hazard (Kates 2001), three central questions seem to persist: What should people and societies worry about? Why do people live and work in areas subject to repeated hazards? How is it that they survive and even prosper in such areas?

Agricultural drought in Australia and Tanzania
Les Heathcote and I were part of an early effort to address these questions globally across the range of natural hazards using the network of the International Geographical Union (IGU). The network undertook standard studies of 10 different natural hazards at 40 sites in 17 countries (White 1974) and in depth national studies of droughts, floods, and tropical cyclones that contrasted an industrialized and developing country (Burton *et al.* 1978).

The drought study contrasted the agricultural drought hazard in Australia with that of Tanzania. I came to Adelaide in 1971 to work together with Les on it. We tried to measure the then current losses from agricultural drought using measures of deaths from the hazard and the economic value of damages (crop and livestock losses, forced sales, and the like). To calculate the full social costs of he hazard, we estimated the individual and societal cost of adaptation as the value of effort expended in trying to abate or prevent these losses. To place the social cost in perspective we compared it with the then (1970s) gross national product. And all of these were expressed in comparable terms such as per capita person at risk to the hazard. (See Table 1).

In Australia, we estimated that a million people of the 13 million population were at risk, although there were no deaths clearly associated with drought. Their production losses averaged over the 66 years of the then available data were $24 in then current US$ per person. Adaptation costs by farmers included irrigation, water provision and conservation, replanting, excess fodder, and the like. Government expenditures included a share of irrigation and water provision, drought relief, emergency water and fodder, warning and information, and research. All told these amounted to $19 $US roughly split between farmers and government. Thus total social costs were $43 $US per person at risk, yet amounted to only 0.10% of per capita gross national product (GNP).

By comparison, in Tanzania deaths due to agricultural drought were estimated to average annually 40 per million of the then 12 million at risk. Damages were estimated at .70 $US and adaptation at .80 $US per person at risk, with total costs of agricultural drought at $1.50 $US per person at risk and equivalent to 1.8% of per capita GNP. The costs of adaptation fell mainly on farm households with 10 days per year for labor invested in reducing possible drought losses. Government expenditures were for research; irrigation, and rural water-supply development; famine relief, food import and storage; and provision for migrants.

From our comparison and the other national studies (Table 1), we learned three important things. Hazard losses varied greatly between the industrialized (Australia, US) and developing (Bangladesh, Sri Lanka, Tanzania) countries using the two basic measures. Developing countries had much larger death rates expressed as the annual average number of deaths (per million at risk), and industrialized countries had much

Table 1: Comparative Natural Hazard Costs* in 1970s

Hazards	Countries	Deaths /10^6 people	Damage /person at risk	Adaptation /person at risk	Social Costs/ person at risk	Cost % GNP
Agricultural Drought	Tanzania	40	.70	.80	1.50	1.84
	Australia	0	24.00	19.00	43.00	.10
Flood	Sri Lanka	5	13.40	1.60	15.00	2.13
	US	2	40.00	8.00	48.00	.11
Tropical Cyclone	Bangladesh	3000	3.00	.40	3.40	.73
	US	2	13.30	1.20	14.50	.04

*Monetary costs are in US 1970s dollars per person at risk. (Source: Burton, Kates and White 1993, pp. 68–74).

larger estimated economic losses as the value of damages sustained (per person at risk). When the costs of adaptation effort expended to prevent these losses were added in to calculate an overall social costs, these total costs were considerably greater than the losses. But when the social costs were compared as the percentage of per capita GNP current at the time, the burden on the developing countries was much greater than that of the industrialized countries.

Now forty years later, human-induced climate change that we did not consider in our original study will almost surely bring more drought to some areas, more floods to others, and possibly more and greater cyclones. In this paper I examine global trends in extreme climatological and weather events and disasters since our original study. I then consider trends in adaptation especially as it is addressed to climate change. For a conclusion, I revisit the three persistent questions

Trends in Events and Disasters

At least two series of global observations of extreme climatological and weather events that resulted in disasters are maintained by the large reinsurance corporations. The series of natural disasters of the Swiss Reinsurance Company (2011) as defined by either economic losses and/or casualties covers the period 1970–2010. Over that time natural disasters rose more than five-fold (see Table 2 and Fig.1). In the series maintained for a shorter period (1980–2010) by the Munich Reinsurance Company (2011), weather catastrophes rose threefold.

Using the longer series of Swiss Reinsurance that parallels my own work with Les, one would expect rising disasters or catastrophes from the combined effects of increasing populations and property at risks. In Table 2 the five-fold global rise in disasters (mostly weather and climate related) are compared to an almost two-fold increase in global population and a four and a half-fold increase in global wealth as measured by economic product. Is there also a possible role of climate change in explaining the increase in extreme events and disasters?

The Intergovernmental Panel on Climate Change (IPCC) as it prepares for its fifth assessment commissioned a *Special Report on Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation* (SREX) As this paper is being

Table 2: Natural Catastrophes, World Population, Gross World Product, 1970–2010, 1970=100

Years	1970	1980	1990	2000	2010
Natural Catastrophes	100	134	359	406	521
Population	100	121	143	162	186
Gross World Product	100	155	237	339	449

Sources: Catastrophes: Swiss Reinsurance (2011); Population and Gross World Product: DeLong (1998) and update to 2010.

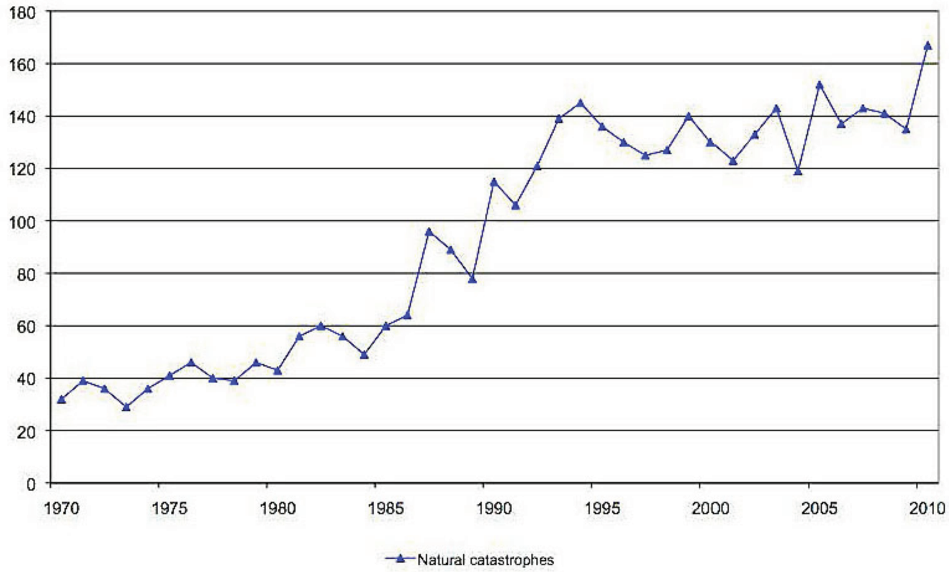

Fig. 1: Number of natural catastrophes, 1970–2010
Source: Swiss Reinsurance 2011

written, the Summary for Policy Makers is available (IPCC, 2012), and the full text will be shortly available. I have ranked, by the reliability of the science, the major findings as to the role of climate change in altering the characteristics of climate-related extreme events and disasters. They are: in the words of the Report's fact sheet:

> *Changing extreme events*
> —Observations since 1950 show changes in some extreme events, particularly daily temperature extremes, and heat waves.
> —It is virtually certain that increases in the frequency of warm daily temperature extremes and decreases in cold extremes will occur throughout the 21st century on a global scale.
> —It is very likely that heat waves will increase in length, frequency, and/or intensity over most land areas.
> —It is very likely that average sea level rise will contribute to upward trends in extreme sea levels and in extreme coastal high water levels.
> —It is likely that the frequency of heavy precipitation will increase in the 21st century over many regions.
> —It is likely that the average maximum wind speed of tropical cyclones (also known as typhoons or hurricanes) will increase throughout the coming century, although possibly not in every ocean basin. However it is also likely there will be either a decrease or essentially no change in the number of tropical cyclones.
> —There is … medium confidence, that droughts will intensify over the coming century in southern Europe and the Mediterranean region, central Europe, central North America, Central America and Mexico, northeast Brazil, and southern Africa.

—Projected precipitation and temperature changes imply changes in floods, although overall there is low confidence at the global scale regarding climate-driven changes in magnitude or frequency of river related flooding, due to limited evidence and because the causes of regional changes are complex.

Thus climate change has already brought us more heat almost everywhere. In my own home region of New England, in the northeast of the U.S., the growing season has already increased by a week and there has been a marked increase in intense 24 hour rainfalls. But the cautious language of the IPCC report (too cautious for some) serves to remind us that recent increases in extreme climate events and disasters or any specific event cannot be simply attributed to climate change.

A recent analysis of major disastrous events in Australia, bushfires from 1925–2009, helps illustrate the point. The 2009 Black Saturday fires in Victoria with its disastrous loss of life (173 deaths) and property (2298 buildings) were the largest in absolute numbers since 1925. The fires coincided with very high temperatures and an ongoing drought and many wondered whether they were influenced by human-induced global warming. But as shown in Table 2, population and wealth also increase over time and historic fire disasters should be considered in the context of current population and wealth. Thus Compton *et. al.* (2010) reconstructed a set of wildfire building and population losses from 1925, normalized (so-called) by inflating past losses proportionate to the 2008/09 building stock and population. By this revision, the 2009 fires were no longer the largest, but fourth in terms of building damage and second in terms of loss of life. A climate link was found with natural climate variations, the El Nino–Southern Oscillations and Indian Ocean dipole phenomena, but not with greenhouse gasses or global temperature.

Even in the midst of extreme events, there is much uncertainty as to their cause or their linkage to climate change. In one study of 24 Australian wheat farmers (Head *et al.* 2011) during the two failed harvest seasons of 2006–2008, the then current drought was perceived as not the normal, one in seven years, but one more extreme and frequent. Yet, there was much uncertainty that it could be attributed to climate change, even among the majority who clearly believed in climate change.

In considering the trends and distribution of disaster losses of the world some forty years later, the SREX Report echoes our findings of 1970:

Trends in disaster losses
—Economic losses from weather- and climate-related disasters vary from year to year and place to place, but overall have increased .
—Total economic losses from natural disasters are higher in developed countries.
—Economic losses expressed as a proportion of Gross Domestic Product (GDP) are higher in developing countries .
—Deaths from natural disasters occur much more in developing countries. From 1970 to 2008 for example, more than 95% of deaths from natural disasters were in developing countries.
—Economic losses from weather- and climate-related disasters have been heavily influenced by increasing exposure of people and economic assets.

With a focus on extreme weather and climate events, the SREX study did not examine extensively the real world situation of the multiple stresses that face people and places impacted by climate change. To explain the causes of disastrous losses, weather and climate events are not solely responsible, but combine with other sources of stress. For example, in the study of New South Wales wheat farmers (Head *et al.*, 2011) farm households struggled not only with major droughts, but also with new deregulated marketing arrangements, and new financial risks. A wine growers and producers study (Park *et al.* 2012) found growers and producers, at the time of the study, not only responding to warmer temperatures and heat stress, but to the global financial crisis, a global oversupply of grapes, changes in consumer preferences, increases in energy costs, and shortages of irrigation water.

Trends in adaptation in times of climate change

People who live and work in high hazard areas survive and even prosper because of their adaptations that lessen the hazard exposure or sensitivity of their household or workplace. In the 1970s, these adaptations were originally called adjustments following Gilbert White's use of the term and the desire to distinguish these from biophysical adaptations in evolutionary science.

First propounded some 70 years ago and published in what might have been the most influential dissertation in geography*,* White (1945) defined adjustment as … 'the human process of occupying or living in an area and the transformations of the initial landscape which result.' Never comfortable with abstractions, White went on to specify at least eight forms of human adjustment to floods: elevating land, abating floods by land treatment, protecting against floods by levees and dams, providing emergency warning and evacuation, making structural changes in buildings and transportation, changing land use to reduce vulnerability, distributing relief, and taking out insurance.

Over time the distinction between adjustment and adaptation was not maintained and adaptation as well as adjustment became enshrined in the literature and now in the international agreements intended to reduce the dangers of climate change. The glossary of the SREX report (IPCC 2012) describes adaptation in human systems as 'the process of adjustment to actual or expected climate and its effects, in order to moderate harm or exploit beneficial opportunities.'

Although adaptation has always been recognized as a needed response to climate change, most of the effort to respond to climate change has emphasized 'mitigation' – the effort to reduce greenhouse gas emissions or to remove them from the atmosphere. Indeed a hostility or skepticism to adaptation was evident for many years, fueled by a concern by advocates of strong action to counter climate change that adaptation was being offered as a way to live with climate change rather than prevent or diminish it. But as it has become apparent that human-induced climate change was occurring, and despite mitigation efforts will increase, interest in adaptation has grown (Pielke *et al*. 2007).

There is already much talk about adaptation but little action. A recent professional literature survey found 1741 documents related to climate change adaptation published between 2006–9 (Berrang-Ford *et al.* 2011*)*, Yet despite this outpouring of studies, only 87 (5%) reported on actual adaptations and most of these involved planning for adaptation rather than specific adaptations to cope with climate change impacts. Much talk but little adaptation is also suggested by an Australian survey.

A baseline study (Gardner *et al*. 2010) was undertaken by the Commonwealth Scientific and Industrial Research Organization (CSIRO) in 2008–9 to measure the type and extent of adaptation activities among 242 organizations, half of whom were business groups or industry representatives in 12 affected sectors and half were state and local government groups, infrastructure management organizations, associations, and non-governmental organizations. Some 40% of the responding groups said they had undertaken adaptation activities but these are characterized in the report as planning activities and no specific adaptations beyond planning or information are listed.

Across the range of climate impacts, there are many potential adaptations, but most of these are incremental, doing slightly more of what is already being done to deal with natural variation in weather and climate. One of the most extensive listings of adaptations to specific climate impacts is that of the U.S. National Research Council's Panel on Adapting to the Impacts of Climate Change (NRC 2010) which lists 314 adaptations in seven different sectors. In reviewing these, I found only 16 (5%) appear not to be incremental in that they had not been tried, at least locally, somewhere in the U.S.

Incremental adaptation in the short-run may also be maladaptive in the long run. In hazard research (Burton, Kates, and White 1993; Kates *et al*. 2007), we labeled this behavior as the levee or catastrophe effect. Incremental adjustments and routine responses, such as building levees along a river or suppressing forest fires had the effect of reducing frequent, low to moderate magnitude losses, and thus increase the short-term land and resource value. Eventually, though, the forest is burned or the levee is over-topped, and human development, enticed into the hazard zone by the apparent success of protection, is catastrophically lost.

Incremental adaptations will also be insufficient as climate change grows, and will require transformational adaptation to climate change impacts. This will be most likely where vulnerability in certain regions, populations, or resource systems is currently high and/or if more severe climate change occurs beyond the likely range of current assessments. Vulnerability may already be high because of physical settings such as the Arctic where the rate of warming is high or in low lying coasts, deltas, and islands. Vulnerable groups include marginally productive livelihoods, poor or indigenous peoples, and the major victims of extreme events, the very young, the elderly, and women generally. The combination of climate change and economic decline or existing poverty can be severe as in the low-lying deltas of Bangladesh, seen by many as the most vulnerable place on earth to climate change.

There are least three sources of severe climate change that can require transformational adaptation. These are changes that go beyond the range of current assessments given the large fossil fuel reserves , the weak international agreements on greenhouse gas (GHG) reductions (Moss *et al.* 2010), and the inability of science to constrain the upper bounds of warming for a given greenhouse forcing (Schneider 2009). Then there are local 'hot spots' or even large regions such as the Arctic where global change is amplified (NOAA 2011) Also, there are possible tipping points that could cause rapid climate change impacts in certain regions or even globally (Lenton *et al.* 2008). All of these leave open a small but significant probability of quite large and perhaps abrupt climate change as anthropogenic forcing grows. The '4 Degrees and Beyond', conference in 2009 was the first to consider how human environmental systems would respond to global warming beyond the range of current assessments (New *et al*. 2011).

Given a need to go beyond incremental adaptations, what might such adaptations be? We describe these as transformational adaptations (Kates, Travis and Wilbanks 2012) and they can be either *responsive*, taking place during and after serious climate change impacts, or *anticipatory*, in advance of threats that pose serious risks. Many transformative adaptations are technological, infrastructural, or process changes., Others are behavioral, affecting how individuals and society make decisions and allocate resources to cope with climate change. Or they may include fundamental changes in institutional arrangements, priorities, and norms.

We envision at least three types of transformative adaptations: those that are adopted at a much larger scale or intensity, those that are truly novel for a specific region or resource system, and those that shift locations or transform places. The leading example of the enlargement of scale and intensity is that of the Netherlands (Deltacommissie 2008), in its current programs of coastal defense ('Weak Links') and riverine flood abatement and water supply ('Room for the River') .These are transformational because of their enlarged scale, intensity and integrated combinations of adaptations, novel approaches (artificial islands), evacuation of some areas (depolderization), as well as new institutions and funding mechanisms.

An example of a novel adaptation is the effort to create water efficient maize for eastern Africa (African Agriculture Technology Foundation 2009). Efforts to breed drought-resistant maize plants in East Africa are not new; the novelty of this effort lies in the use of new breeding techniques (both conventional and biotechnological), a package of best agronomic practices with cost-free distribution to farmers over 25 years, and the unique public private partnership (International Maize and Wheat Improvement Center, the Monsanto Corporation, five National Agricultural Research systems, and the Gates and Buffet Foundations).

Some adaptations collectively transform places or shift such systems to other locations. Resettlement associated with climate variability, and, by some accounts, climate change *per se*, is beginning in a few places (de Sherbenin *et al.* 2011) including Arctic villages (US ACE 2010, Ford *et al*. 2010) and Pacific islands (Burkett 2011). Anticipating future evacuation, one Australian aid project is currently preparing islanders for livelihoods in Australia (Reed 2011). Other transformative shifts are underway in Australia as for example, wine growers and producers purchase Tasmanian properties to diversify their holdings to cooler areas (Park *et al*. 2012).

Persistent questions, persistent answers
In the 70 years of modern geographic research on hazards, three central questions have persisted: What should people and societies worry about? Why do people live and work in areas subject to repeated hazards? How is it that they survive and even prosper in such areas?

What should people and societies worry about?
When Les and I worked together as part of the IGU study, we assumed that natural hazards were important enough to collectively worry about them. We did so in part because of our place-based studies in which we came to both respect and worry about those who lived and worked in hazard prone areas. But also because we were interested in the relationship between nature and society. One way to study that relationship is to study the extremes of those resources or services most essential for human sustenance and those hazards that most threaten human life and livelihood. This strategy persists to this day and on the resource side has had a major revival with the concentration of study over the last decade on ecosystem services (Daily *et al.* 2000).

One way of addressing what to worry about was to sum up the trends in natural hazards losses and gains up to 1973. Thus I helped write:

> *To sum up, the global toll of natural disasters rises at least as fast as the increase of population and material wealth, and probably faster. In developing countries, disasters may be less frequent but are more catastrophic and more costly in lives.* (Burton, Kates and White 1978, p. 2).

Today, with the hindsight of four decades, I would add some additional observations. Many kinds of losses are still uncounted and the net benefits of locations and land use subject to hazard events are rarely measured. It is also rare that climate alone can cause disasters as we increasingly recognize the multiple stresses that contribute to disaster loss.

While loss of life from natural hazards is still large it is has declined rapidly in the industrialized world (despite the Japanese tsunami) as well as in the developing world (albeit more slowly and despite the enormous loss from the Haitian earthquake). Losses of life have declined much more on a relative scale when growth in population is taken into account and when non-climate disasters (earthquakes) are excluded. Finally, the assumption that the number of extreme events averaged over decades was essentially stationary has come into question given human-induced climate change and some extreme events are actually rising. Climate change increases the number and intensity of extreme weather and climatic events, the people and places exposed to them, and their sensitivity to these events.

Why do people live and work in areas subject to repeated hazards?
In my own dissertation (Kates 1962), I asked this question of residents and users of a small flood plain in LaFollette, Tennessee, U.S. I knew that people live and work in flood plains for a variety of locational reasons including certain intrinsic advantages to flood plain location. But why do people persist in living and working in areas subject

to repeated flood? After conducting extensive interviews, I learned more of why flood plain users or residents did not seem unduly concerned about floods despite the opinions of technical personnel or even repeated flood experience. They had a variety of personal perceptions of hazard and potential loss that somewhat rationally lead them to ignore flood hazard. There perceptions ranged from simple ignorance to various expectations that they would not experience a future flood or bear a serious loss. Les had similar observations for agricultural drought as did the authors of the recent fine-grained study of wheat farmers (Head *et al*. 2011).

But beyond such individual differences, is there a larger, common, explanation for living in recurrent hazardous areas? One of our earliest insights was in the relationship between hazards and resources. People encounter hazard, we thought, in the search for the useful. For example, places that provide easy access to several different ecosystems or resource locations are often sites of high natural hazard – earthquakes where mountains meet the sea, coastal storms at land's end, floodplains with fertile soils and easy access, and drought where dry lands border the damp.

How is it that they survive and even prosper in such areas?
People who live and work in high hazard areas do so through a huge number of adaptations that allow them to reduce their hazard exposure, diminish their sensitivity, and increase their capacity to undertake adaptations. These have always been a mix of individual and collective actions. For example, farmers dealing with agricultural drought have always required the collective and anticipatory adaptations that improved their crops and cropping practices, created storage, provided irrigation, or roads for marketing . But the need for collective, anticipatory, and transformational adaptations will only increase with climate change. New research on transformational adaptation should enter our geographic priorities as it already seems to have done so in Australia. In our recent U.S. National Research Council study on adaptation, we made a special effort to be briefed on Australian experience and research which we considered exemplary. We were not disappointed.

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