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Transformational adaptation when incremental adaptations to climate change are insufficient

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All human–environment systems adapt to climate and its natural variation. Adaptation to human-induced change in climate has largely been envisioned as increments of these adaptations intended to avoid disruptions of systems at their current locations. In some places, for some systems, however, vulnerabilities and risks may be so sizeable that they require transformational rather than incremental adaptations. Three classes of transformational adaptations are those that are adopted at a much larger scale, that are truly new to a particular region or resource system, and that transform places and shift locations. We illustrate these with examples drawn from Africa, Europe, and North America. Two conditions set the stage for transformational adaptation to climate change: large vulnerability in certain regions, populations, or resource systems; and severe climate change that overwhelms even robust human use systems. However, anticipatory transformational adaptation may be difficult to implement because of uncertainties about climate change risks and adaptation benefits, the high costs of transformational actions, and institutional and behavioral actions that tend to maintain existing resource systems and policies. Implementing transformational adaptation requires effort to initiate it and then to sustain the effort over time. In initiating transformational adaptation focusing events and multiple stresses are important, combined with local leadership. In sustaining transformational adaptation, it seems likely that supportive social contexts and the availability of acceptable options and resources for actions are key enabling factors. Early steps would include incorporating transformation adaptation into risk management and initiating research to expand the menu of innovative transformational adaptations.

All human–environment systems adapt to climate and its natural variation. Adaptation to human-induced change in climate has largely been envisioned as increments of these adaptations intended to avoid disruptions of systems at their current locations. In some places, for some systems, however, vulnerabilities and risks may be so sizeable that they can be reduced only by novel or dramatically enlarged adaptations, the reorganization of vulnerable systems, or changes in their locations. These are increasingly recognized in the climate impacts literature as transformational adaptations (refs. 1–3; ref. 4, p. 187; refs. 5, 6).

This perspective considers four key questions of transformational adaptation, beginning with its definition, the need for transformation, the difficulties associated with its implementation, and ways in which transformational adaptation can be initiated and sustained.

What Is Transformational Adaptation?

We think of incremental adaptations to change in climate as extensions of actions and behaviors that already reduce the losses or enhance the benefits of natural variations in climate and extreme events. For example, in one extensive listing of adaptations to climate change, the US National Research Council's Panel on Adapting to the Impacts of Climate Change (4) lists 314 adaptations to specific climate impacts in seven sectors: agriculture and forestry, coastal areas, ecosystems, energy, health, transportation, and water resources. Of these, only 16 (5%) appear not to have been tried, at least locally, somewhere in the United States. That there are many potential adaptations and most of these are incremental and familiar—doing slightly more of what is already being done to deal with natural variation in climate and with extreme events—is further confirmed by recent surveys of proposed (7) or adopted (8) adaptations. For example, of 31 health sector "action examples" listed in (supplementary material in ref. 7), 28 seem to be incremental adaptations of current health-related actions.

Differing from incremental adaptations, there are at least three classes of adaptations that we describe as transformational: those that are adopted at a much larger scale or intensity, those that are truly new to a particular region or resource system, and those that transform places and shift locations. In most of our examples, these are collective adaptations that would be explicitly planned and implemented, but they also include autonomous adaptations by individuals and organizations that can cumulate in transformative adaptations, or actions intended to address other problems that can become transformative climate change adaptations (as in the case of the regreening of the Sahel described later).

These transformative adaptations, like incremental responses, can be responsive—taking place during and after serious climate change impacts—or anticipatory, in advance of threats that pose serious risks of very painful impacts. Although many transformative adaptations are technological, they are also behavioral, affecting how individuals and society make decisions and allocate resources to cope with climate change. They may alternatively include fundamental changes in institutional arrangements, priorities, and norms. For example, proposed changes in the water rights system in the American West, as well as other longstanding resource allocation mechanisms (9, 10) could qualify as transformative, although associated land uses might change very little at first.

The differences between incremental and transformational adaptations may not always be clear-cut. For example, are extensive seawall constructions transformational? Probably if they are larger than those traditionally built in an area and if they fundamentally change coastal land uses, such as the community-encircling dikes and inlet barriers proposed for the Gulf Coast in the United States (11), but probably not if all they do is protect existing land uses. It is also possible that, over the long run, the cumulative incremental changes may coalesce into what appears in retrospect as a transformational adaptation, a process that may be well under way because of the rapidity of Arctic climate change among the Inuit peoples of Canada (12) or because of warming for the wine makers of Australia (13). Thus, some adaptations may be difficult to

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categorize and may constitute an intermediate class, especially dependent on the scale of analysis. These include adaptations that are transformational for some scales but not others, incremental adaptations that are sustained over a long enough time that their cumulative effect is transformational, and institutional changes in adaptive thinking and adaptive capacities that improve the capacity to undertake transformational change, even if current projections of threat do not call for that decision to be made now. Nonetheless, despite this blurring of differences, the distinction between incremental and transformational is relatively clear in the following examples.

Enlarged Scale or Intensity. Common adaptations can become transformational when they are used at a greater scale or in integrated combinations with much larger effects than before. The current regreening of the Sahel, the drought-prone belt of West Africa bordering the Sahara, is an example of autonomous action by individual small farmers addressing problems other than climate change that accumulated into a transformative adaptation. Farmers in the southern regions of Niger whose woodlands had been declining from drought and population growth began to adopt a technique in the 1980s that came to be known as farmer-managed natural regeneration. This method used the web of tree roots beneath a farmer's fields that regularly sprouted and were previously treated as weeds to provide a continuing tree stock that could be selected, pruned, and allowed to grow, providing scattered trees amid the fields. The trees provided food, animal fodder, and fuel, as well as protected the crops from wind and evaporation. So widespread has been the adoption of farmer-managed natural regeneration that satellite images find approximately 5 million hectares observable as a green belt that will be highly resilient to climate change (14, 15).

An example of an anticipatory transformational adaptation is laid out in the Thames Estuary 2100 Plan (16). In what is considered a model of current flood adaptation, the city of London and adjacent suburbs have been protected since 1984 from flooding, high tides, and storm surges on the Thames River estuary by an engineered barrier at Woolwich that can be raised or lowered. Nevertheless, mindful of potential rising sea level from climate change, the UK Environment Agency began in 2002 a study of flood management risk for the next century. Predicated on a sea level rise of 1 m (and a possible rise of as much as 2.6 m), 10 estuary-wide options were identified to manage the rising water levels. In the first 25 y, the current system will be maintained and adjusted incrementally, followed by major enlargement and replacement of the current tidal defenses. After 2060, depending on the degree of climate change, transformative options would be considered, including a new, higher barrier at a different location and relocation of development from the floodplain.

New Adaptations. New adaptations may be truly novel or they may never have been used at the site of a particular human–environment system. An example of novel adaptation is the effort to create water-efficient maize for Africa. Maize is the major food and cash crop in much of Africa, especially the eastern portion. Drought currently affects maize production and is expected to increase in many places with climate change. A unique public/private partnership was begun in 2008 by the African Agriculture Technology Foundation (17) to create higher yielding drought-tolerant maize varieties and to distribute the seed to farmers in Kenya, Mozambique, South Africa, Tanzania, and Uganda for a period of 25 y without royalties and along with best agronomic practices. To develop the novel varieties, a combination of the International Maize and Wheat Improvement Center, the Monsanto Corporation, the five National Agricultural Research systems, and the Gates and Buffett foundations will use conventional and marker-assisted breeding and biotechnology. Efforts to breed drought-resistant maize plants in East Africa are not new; the novelty of this effort lies in the mix of institutional and technological actions, the combination of partners (local, national, global), the new breeding techniques, the inclusion of other best agronomic practices, the cost-free distribution to farmers, and the extended time horizon.

New adaptations are created by transferring existing adaptations to new locations where they are transformative. For example, crop insurance against weather loss has long been available in developed countries, but not in developing countries. Pilot studies of African weather-indexed crop insurance have been conducted or are under way in a number of countries including Kenya, Malawi, and Ethiopia (18). Water resource examples of proposed or actual transfers of existing adaptations to new locations include the desalinization of seawater into fresh water in California, where a water system based on surface runoff for more than a century is turning to ocean water and identifying sites for future desalinization plants (19), and a treatment plant to recycle waste water for uses other than human consumption built in Kings County, WA (ref. 4, p. 55). Relocating species intentionally as climate changes is a subject of controversy, but some experimental assisted colonization has already begun (refs. 20, 21).

Different Places and Locations. Some adaptations collectively transform place-based human environment systems or shift such systems to other locations. Resettlement associated with climate variability, and, by some accounts, climate change per se, is already under way in a few places (22). Climate change in the Arctic occurs at twice the rate in more southerly locations. Twenty-six villages in Alaska are already experiencing increased coastal or riverine erosion, and an additional 69 rural villages are or will experience major climate change impacts that could force their relocation (23). Although the need for relocation has been recognized for more than 15 y and funding has been authorized for 5 y, no such relocations have yet taken place, illustrating the institutional difficulties for undertaking relocation (ref. 4, p. 78). An earlier experience elsewhere in the United States, community relocation after the Mississippi River flood of 1993, yielded only small reduction in exposure while development elsewhere in the floodplain placed more property at risk (24). Pacific islands are threatened by rising sea levels. The Carteret Islands in Papua New Guinea are cited as perhaps the first case of residents migrating (to Bougainville) as a result of sea level rise (25). Anticipating their future evacuation, one Australian aid project is currently preparing islanders for livelihoods in Australia (26).

The most ambitious transformational adaptation program is that of The Netherlands, involving elements of all three types of transformational adaptation. With a history of extensive water management dating back to the ninth century, it is not clear which adaptations are truly new, but the current programs of coastal defense ("Weak Links") and riverine flood abatement and water supply ("Room for the River"), by their extent and approach (27), are transformational because of their enlarged scale, intensity and integrated combinations of adaptations, and novel approaches, like artificial islands, evacuation of some areas, as well as new institutions and funding mechanisms. The river project represents a major change from traditional Dutch flood control of building levees and increasing the height of the existing levees. Instead it allows for increased flows of the Rhine and Meuse rivers by giving them more room through deepening the channels and enlarging flood plains, lowering groins, removing obstructions, shifting levees inland, and allowing some polders to flood. Building on these extensive short-term projects, a long-term effort is being developed by the Delta Commission to adapt to high-end projections of sea level rise, storm surges, increased precipitation, and drought expected with future climate change (28). Among other innovations, this includes a planning horizon of more than two centuries, increasing the overall level of flood protection tenfold, and creating long-term funding of at least 1 billion Euros per annum (27).

Why Might Transformational Adaptation be Needed?

Two conditions set the stage for transformational adaptation to climate change impacts: large vulnerability in certain regions, populations, or resource systems; and severe climate change that threatens to overwhelm even robust human–environment systems.

Very Vulnerable Regions and Activities. Some regions and resource systems are especially vulnerable to climate change because of their physical setting, vulnerable populations, marginal productivity, or combinations of all of these (1). Vulnerability to climate change and its impacts often occurs as a product of multiple stresses combining climate change with other place or group vulnerabilities (29). Low-lying islands are vulnerable to modest sea level rise, with some already on the verge of significant outmigration (22). Existing water shortages (e.g., in the Colorado River basin) or current beach erosion (e.g., Arctic Slope of the United States and Canada) can be intensified by even moderate climate change. Alternatively, the combination of climate change and economic decline or existing poverty can be severe. Most vulnerable are the low-lying deltas as in Bangladesh, with their large impoverished populations. In a review of 87 adopted adaptations between 2006 and 2009 (8), 56% focused on vulnerable regions (e.g., Arctic, coasts) and 60% on vulnerable groups (e.g., socioeconomic, indigenous, women, elderly people, children). In only 19% was climate change the sole motivating factor.

Some incremental adaptation in the short run may prove maladaptive in the long run, setting up the need for system transformations. This process is termed the risk spiral in coupled natural and human systems, and the levee or catastrophe effect in hazard research (30–34). Incremental adjustments and routine responses, such as suppressing forest fires or building levees along a river, can have the effect of reducing frequent, low- to moderate-magnitude losses, and thus increase land and resource value and short-term returns on investment. Eventually, although, given our inability to engineer extremes out of the system, the forest eventually burns or the levee is overtopped, and human development, enticed into the hazard zone by the apparent success of protection, is catastrophically lost. How such effects might play out in adapting systems like the Thames Barrier to climate change deserves much more research.

Very Large Climate Change. Transformational adaptation could also be driven by severe climate change, which can take at least three forms: changes beyond the likely range of current assessments, local "hot spots" where global change is amplified, or tipping points that cause rapid climate change impacts in certain regions or globally. Weak international agreements on greenhouse gas reductions, large fossil fuel reserves, potential tipping elements in the climate system, and inability of science to constrain the upper bounds of climate sensitivity (i.e., warming for a given greenhouse forcing) leave open a small but significant probability of quite large and perhaps abrupt climate change as anthropogenic forcing grows (35–37, 5). The natural science literature on severe climate change has grown recently, especially focused on extreme events (38), sea level rise (39), and abrupt change (40), underlined by new greenhouse gas concentrations scenarios (41), but very few studies have examined adaptation to very severe climate change (42, 43, 24). A first-of-its-kind conference, "4 Degrees and Beyond," was held in 2009 to encourage thinking about how social and ecological systems would respond to global warming at the upper end of current projections (44).

Why Is Anticipatory Transformational Adaptation Difficult to Implement?

The main barriers to implementation of anticipatory transformational adaptation are (*i*) uncertainties about climate change risks and adaptation benefits (45), including the unimaginable nature of possible extreme vulnerabilities and impacts (46, 47); (*ii*) the perceived costs of transformational actions (e.g., ref. 48); and (*iii*) a suite of institutional and behavioral barriers that tend to maintain existing resource systems and policies (49).

Uncertainty. Both major drivers of transformational adaptation—high vulnerability and large climate change—are also uncertain. Except for the most vulnerable places (e.g., very low-lying islands or deltas), growing losses from extreme events may initially be interpreted as the result of expanding development or an unfortunate run of long-experienced events (e.g., droughts, floods, heat waves, storm surges, wildfires). The impacts of warming exceeding 4 °C or tipping point events may appear unimaginable both to science and to the lay public. The benefits of transformational adaptation are also uncertain. The efficacy of truly novel adaptations is untested. In addition, most transformational adaptations present costs that are uncertain but appear daunting.

Costs. Transformative adaptations often require large initial investments, with the benefits in avoided impacts realized only well into the future. The costs of some transformational adaptations that are enlargements or elaborations of familiar adaptations can often be estimated by extrapolation, and the costs of novel adaptations and location changes are unknown but presumed to be high. In the case of some autonomous transformative adaptations, the individual costs may not be high, but the general presumption of high transformative costs acts as a barrier. Some estimates are available for protection from sea-level rise. A 1-m rise threatens $100 billion of property in California, and extended and enlarged coastal infrastructure to protect that property run to $14 billion capital costs and 10% annual operation and maintenance costs (50). An integrated system of sea walls and inlet barriers recently proposed to protect a 60-mile section of the Texas coast from the storm surge hazard would require as much as a $10 billion initial investment (51). The transformational option for protecting the Thames estuary is estimated to cost £4.2 billion (16). Beginning in 2020, The Netherlands proposes funding its ambitious integrated program for floods, drought, and coastal protection with 1 billion Euros per year (27). Little is known about relocation costs or other transformational changes in land use, although initial estimates for relocating Alaska coastal communities are from $20 to $200 million each for villages of 250 to 600 inhabitants and associated infrastructure (23). Minimum estimates could be based on current property values. For example, irrigated farm land in the US Midwest and Great Plains is approximately twice as valuable as dry-land crop land, and uncropped rangeland is less than half as valuable as dry-land cropland. Thus, a hypothetical transformation from irrigation to dry land to grazing land use under a drying climate in the Great Plains would occasion at least a halving of land value at each transition, integrated across millions of acres of current farmland. The transfer of water from agricultural to urban locations and uses in the American West comes at a double to 10-fold cost per unit; such water transfers also illustrate the general principle that costs and benefits are differentially experienced and perceived among different groups (e.g., urban vs. rural dwellers).

Institutional and Behavioral Barriers. Barriers to transformational adaptation include legal, social, and institutional conceptions of rights, longstanding resource allocation policies, customary protection and entitlements, and behavioral norms.

Many longstanding resource systems are founded on strong rights-based access to resources (e.g., water rights) or traditional uses and privileges (e.g., use of public or common lands for livestock grazing). Private property rights confer the strongest form of control over a resource, and land use restrictions that might, for example, curb development in flood and wildfire risk zones are difficult to implement. Longstanding resource allocation policies, such as the Colorado River Compact of 1922 in the United States, were designed specifically to provide policy stability so that users could make long-term investments in water infrastructure (52), a stability no longer realized with climate change. Customary government protections from floods, wildfire, predators, and a host of other threats as well as relief from disaster losses tend to limit adaptation to incremental change, if any (53–55). Additional brakes on transformational adaptation come from the anchoring of current patterns in ingrained behaviors. Conceptions of self-identity and sense of place and preferences for stability over disruption make relocation very difficult. Ease of falling back to familiar patterns of action, especially if they have been useful in the past, make mobilizing and managing activities/events outside the range of experience problematic. Some aggressive adaptations may appear to violate longstanding and sometimes hard-won standardized practices and deeply ingrained rules of thumb. For example, it is taboo in conservation practice to purposefully introduce exotic species to a habitat. However, if needed to preposition some long-lived species into climate change refugia, land managers will have to transform accepted practice (56, 57, 20, 21).

How Might Anticipatory Transformational Adaptation Be Implemented?

Implementing transformational adaptation requires effort to initiate it and then to sustain the effort over time, and frequently long periods of time. In initiating transformational adaptation, it seems likely that external drivers in the form of focusing events and multiple stresses are important combined with local leadership. In sustaining transformational adaptation, it seems likely that supportive social contexts, especially if they are combined with incentives, and the availability of acceptable options and resources for actions are key enabling factors.

External drivers for transformational adaptation could be both dramatic focal events such as major floods and wildfires that are unavoidable reminders of vulnerabilities and other sources of stress that also serve as “policy windows” to encourage considerations of major changes (58, 59). Such focal events may occur in the adapting locale itself, or they may occur in other locales whose vulnerabilities seem similar. Some limited evidence indicates that extreme events may provide incentives to adapt (60), and infrastructure lifecycle studies in Alaska show that extreme events can act as pacemakers for adaptive actions (61). It will also be helpful if monitoring and alert systems are in place to offer early detection and warning if severe or abrupt climate change should emerge (40). The consideration of adaptations that might otherwise be unimaginable is more likely in a multistress context, in which pressure for changes come from a number of directions and a transformational adaptation would offer relief from multiple pressures: environmental, economic/financial, sociopolitical—in a sense, a fresh start toward a more attractive future.

Internal driving forces toward transformational adaptations include effective adaptive institutions combined with public values and attitudes and the availability of understandable and socially acceptable options, along with incentives and resources for action and leadership. Supportive social contexts are those that respond to stresses of all types with broad-based participative problem-solving and vulnerability assessment, combining adaptive institutions (62, 63) with supportive public attitudes (64, 65) to facilitate the consideration of a wide variety of risks and responses. US case studies reflecting such adaptive strategies at work include King County, WA; Keene, NH; New York City; and Chicago (4). More generally, such capacities benefit from structures for monitoring emerging stresses and threats, iteratively evaluating possible courses of action, and seeking innovative approaches to reducing major risks.

If a community or system perceives that transformation might be needed to avoid a catastrophic disruption, it helps to be able to consider alternative pathways for its future with which local decision-makers and stakeholders can imagine living, that could be undertaken through local initiative [rather than being rooted in components of the system that are externally controlled (e.g., ref. 66)], and that are associated with understandable, acceptable, and affordable options. As transformational adaptation often appears to represent levels of cost that decision-makers simply do not consider feasible, further consideration is likely to stop unless there are ways to share costs, to access other financial and managerial resources, or to reframe the considerations. Costs can be shared by purpose (e.g., job creation or ecosystem services), by source (e.g., higher levels of governance or industry), or by time (e.g., shifted to the future or endowed by an annual fund). Costs can also be reconsidered, as in the costs of a failure to act; in many cases, it is useful to seek transformational adaptations that offer “cobenefits” with respect to other societal agendas (4).

Leadership is especially important in initiating transformational strategy and action (67, 68). Examples include the roles of County Executive Ron Simms in catalyzing climate change adaptation planning in King County, WA (15, 69), and Mayor Michael Bloomberg of New York City in developing a Climate Change Adaptation Task Force (4). Leadership often benefits significantly from the presence of incentives, including ancillary benefits of transformational adaptive actions.

Early Steps Toward Anticipatory Transformational Adaptation

Given barriers to anticipatory transformational adaptation, but also factors that could facilitate it where it seems the best course of action for risk management, what steps should be pursued to make it a part of responsible adaptive management? Two actions appear to be the keys: incorporating transformation adaptation in frameworks of thought about risk management and initiating research to expand the menu of innovative transformational adaptations.

Incorporating Transformational Adaptation in Frameworks of Thought About Risk Management. In addressing climate change uncertainties, the conventional answer is to take steps to reduce uncertainties about climate change; however, in most cases, the more promising approach is to promote risk management given uncertainties (4). As in the case of more than a half century of attention to reducing risks of nuclear war, and as in the lives of every person facing routine and risky choices, making decisions in contexts that recognize and weigh uncertainties is more common to life than requiring uncertainties to be minimized before acting. Thus, transformational adaptation should be considered early in efforts on risk management.

Many of the approaches that support such a broadening of risk management practices are relatively unthreatening to implement. Communities can undertake a continuing process of participatory vulnerability assessments, including consideration of possible future threats of disruption to current systems, which is increasingly viewed as a fundamental part of climate change risk management. Monitoring and assessing emerging threats can be helpful, including relevant local experiences that suggest possible major consequences at a later time, as well as relevant focusing events elsewhere. Contingency planning exercises can convert the unimaginable into the imaginable—not initially as proposals for action, but as a "what-if" proposition for discussion, for reconsidering strategies in connection with iterative learning from the monitoring and assessment process.

Expanding the Menu of Innovative Transformational Adaptations. Research on innovative options for transformational adaptation includes the range of such adaptations: technological, institutional, and behavioral, with particular attention to issues such as social acceptability and socioeconomic affordability. The National Research Council's Panel on Adapting to the Impacts of Climate Change lists approximately 29 research needs by sector, many of which would provide support for transformational adaptation (4). Among technologies, research on desalinization (70) and solar-assisted cooling and air conditioning (71) seem particularly promising. Major institutional changes in property rights and water law and treaties (e.g., ref. 10) will be required, and research can better define needed changes and ways of achieving them. Technological and institutional change that can facilitate relocation out of highly vulnerable regions is a major research challenge. Some important research directions that can support relocation include the creation of new infrastructure siting and design standards (72); novel land use instruments, such as rolling easements that allow for timely response (73); and research into prospects, mechanisms, and costs for assisted relocation of natural species (20) and human populations (22).

Conclusion

In summary, transformational adaptations will be required in future years in some places and by some systems, given local vulnerabilities and in the face of such possible driving forces as relatively severe climate change and other stresses. If serious disruptions are to be avoided, vulnerable parties should consider anticipatory transformations. Barriers to anticipatory transformations are often daunting, as a result of such challenges as uncertainties, perceived high costs, and institutional inertia. Where vulnerabilities and risks could be of great concern, however, it is possible to identify conditions that would support the initiation of broad-based societal consideration of transformative actions. Monitoring and learning from emerging changes of conditions that confirm these vulnerabilities can lead to decisions that would avoid especially disruptive futures through voluntary transformations.

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