Popul Environ (2018) 39:319–338
https://doi.org/10.1007/s11111-017-0290-2

ORIGINAL PAPER

Thresholds in climate migration

Robert McLeman[1]

Published online: 13 December 2017

Abstract Migration in response to climatic hazards or changes in climatic conditions can unfold in a variety of ways, ranging from barely observable, incremental changes in pre-existing migration flows to abrupt, non-linear population movements. The adoption of migration instead of in situ adaptation responses, and the high degree of variability in potential migration outcomes, in part reflects the presence of thresholds or tipping points within the processes of human-environment interaction through which climate adaptation and migration take place. This article reviews and makes linkages between existing research in climate adaptation, migration system dynamics, residential preferences, and risk perception to identify and explore the functioning and importance of thresholds. Parochial examples from the author's published research on climate adaptation and migration in rural North America are used to illustrate. Six types of thresholds in response to climate hazards are identified: (1) Adaptation becomes necessary; (2) Adaptation becomes ineffective; (3) Substantive changes in land use/ livelihoods become necessary; (4) In situ adaptation fails, migration ensues; (5) Migration rates become non-linear; and (6) Migration rates cease to be non-linear. Movement across thresholds is driven by context-specific characteristics of climate events, natural systems, and/or human systems. Transition from incremental to non-linear migration can be accelerated by people's perceptions, by actions of influential individuals or groups, and by changes in key infrastructure, services, or other community assets. Non-linear climate migration events already occur at local and sub-regional scales. The potential for global scale, non-linear population movements later this century depends heavily on future greenhouse gas emission trends. The ability to identify and avoid thresholds that tip climate migration into a non-linear state will be of growing concern to policy makers and planners at all levels in coming decades. This article forms part of a special issue of this journal dedicated to the late Graeme Hugo, and the author draws heavily on past research by Professor Hugo and colleagues.

✉ Robert McLeman
rmcleman@wlu.ca

[1] Department of Geography and Environmental Studies, Wilfrid Laurier University, 75 University Ave. W., Waterloo, ON N2L 3C5, Canada

Keywords Climate migration · Climate adaptation · Threshold · Tipping point · Non-linear behavior · Migration dynamics · Residential preference · Risk perception

Introduction

In the field of environmental migration, and particularly on questions of how climate change may influence future migration patterns, Graeme Hugo was the sharpest mind going. As with other contributors to this special issue, Professor Hugo was an important influence on my scholarly career, and his unexpected and premature passing stunned and saddened all of us. In this article, I take up a subject to which Professor Hugo had given considerable thought over the years, that of thresholds in climate-related migration. Hugo (in Bardsley and Hugo 2010) used as his departure point a simple definition offered by Meze-Hausken (2008, p. 4), that the term 'threshold' describes a situation where, through the initiation of some sort of stimulus, 'something happens that otherwise would not happen'. In the context of climate-related migration, thresholds reflect particular aspects or properties of natural systems, of human systems, or combinations of both.

The importance of thresholds goes to the very root of (1) how we understand the potential impacts of climate change on global, regional, and local patterns of population movement, and (2) the future implications such population movements will have on sending and receiving communities. In a previous issue of this journal, Bardsley and Hugo (2010, p. 242) asked a simple but challenging question:

> Will migration be influenced by climate change in a linear manner or will there be thresholds or tipping points where fundamental changes to migration levels and patterns result?

Using a migration systems approach, the authors sought an answer to their own question by reviewing case studies of environmental migration in Nepal and Thailand completed for the Asian Development Bank (Hugo et al. 2009; Asian Development Bank 2012). In doing so, they suggested that interactions between climate and human systems could lead to either incremental or non-linear migration outcomes depending on the context and that this in turn depended in part on whether one is looking at the direct impacts of climate change on populations (e.g. severe storms that damage housing) or the indirect ones (e.g. impacts on environmental or societal processes that have a knock-on effect on migration, such as changes in precipitation regimes that affect crop production). They concluded by emphasizing that non-linear changes in migration present the greatest challenges for planners and policymaking and, indeed, for affected populations.

In their study, Bardsley and Hugo (2010) focused on the scale and nature of environmental changes attributable to climate change and the ability of exposed populations to cope with and adapt to such changes without having to move or relocate (described as 'in situ' adaptation) versus those situations where people tend to migrate (or indeed, have no alternative but to migrate). In the present article, I drill more deeply into this question of thresholds in climate-adaptation-migration processes, drawing upon studies that both pre- and postdate Bardsley and Hugo's work, and illustrate key points with parochial examples from my own past research. I will show how there are multiple thresholds—or tipping points, as they are popularly known—within the processes through which climate-related migration unfolds, and these are products of the decision-making of individuals and households as well as the larger group dynamics of migration. The tipping point at which migration patterns and/or volumes become non-linear is situated downstream of a number of other critical thresholds that individuals, households, and communities cross as they adjust and adapt to shifting climatic conditions. As Bardsley and Hugo suggested, thresholds are indeed highly context specific, reflecting the nature of the particular climatic condition or event in question, as well as a wide range of socioeconomic processes and the perceptions of individuals and groups regarding the risks they face and the adaptation options they have at hand. Thresholds are easily recognized after the fact, and so a key challenge in preparing for future climate-related migration is being able to identify and anticipate tipping points and their potential effects before they are encountered. I argue below that this may be possible in many situations.

It must be emphasized that thresholds are just one small (but important) feature of climate adaption and migration processes, which are in turn a subset of larger social systems and processes. Readers seeking a broader analysis of migration systems and their functioning are encouraged to sample widely from Graeme Hugo's considerable inventory of publications (my own favourites include Hugo 1996, 1998, 2005, 2008) and to also consult, among others, Castles et al. (2013), de Haas (2010), Fawcett (1989), King and Skeldon (2010), Mabogunje (1970), and Massey (1990). For a particular focus on climate-related migration systems, reliable options include Hugo (2011), Hugo and Bardsley (2014), Black et al. (2011), and McLeman (2014). The reader should also be aware that what follows is not a systematic review of the literature on thresholds in migration or climate adaptation, but an attempt to link together insights from significant but previously unconnected works in demography, migration studies, sociology, and climate adaptation research and thereby encourage further development and refinement of research in this area.

Three initial thresholds in climate adaptation: the need for adaptation, the failure of adaptation, and disruptive changes to land use or livelihoods

In climate change impacts research, the term 'adaptation' is commonly used to describe actions that are taken to reduce the vulnerability of people, systems, or infrastructure to climate-related hazards (IPCC 2014). Adaptation may be undertaken by a range of actors (from individuals and households to governments and institutions), at a variety of scales (from the local to the global), and proactively in anticipation of future climatic risks, or retroactively, after such risks are experienced (Smit and Wandel 2006). Migration is a potential type of adaptation individuals or households may undertake in response to climatic hazards (McLeman and Smit 2006; Tacoli 2009; Black 2011). People exposed to climatic hazards who have no alternative but to relocate are generally referred to as involuntary or forced migrants or displaced people, while people who wish to move away from an area affected by a given climate risk or hazard but lack the means to do so are described as immobile or trapped populations (Black et al. 2013). Population movements that fall between these two extremes can be described generally as 'adaptive migration' and are often driven not solely by climate-related considerations, but also by a wide range of potential cultural, economic, and social considerations (Foresight 2011).

In a study that is highly consistent with Graeme Hugo's work, Adger et al. (2009) describe three distinctive types of thresholds in climate adaptation. The first type of threshold is encountered when a given climatic event or condition stimulates or necessitates an adaptation response; that is, this threshold represents a moment in space and time where adaptation measures are required when previously they were not. An example of this—one that I borrow from my own research on drought adaptation and migration in Canada's Prairie provinces in the 1930s (McLeman et al. 2010)—would be a situation where the amount of soil moisture on a wheat farm is insufficient for wheat plants to germinate properly and set seed heads. This situation arises on the Prairies in years when below-average rainfall and above-average temperatures coincide in the months of May and June, desiccating the soil and stunting the development of young wheat plants. In the absence of an intervention by the farmer—usually irrigation—the crop can fail in these situations, and the farmer will receive no income from it. This first adaptation threshold is labelled as point 1 on Fig. 1.

Adger et al. (2009) identify a second threshold, at which adaptation ceases to have any beneficial effect. This is labelled as point 2 in Fig. 1. Continuing the example from above, this would occur when conditions are so hot and dry that the wheat crop fails no matter how much the farmer irrigates. Such conditions occur infrequently, but are not unheard of, and often reveal variations in soil quality, drainage, and other local, non-climatic factors that influence productivity at the farm or field level. Should hot, dry conditions become a persistent problem, a farmer who wishes to continue producing wheat may decide to experiment with a variety of other farm-level adaptation strategies, such as adopting more drought-resistant varieties, switching from spring-planted varieties to winter-planted varieties (so as to change the timing of crop germination), or investing in additional irrigation capacity (all such adaptations have been implemented

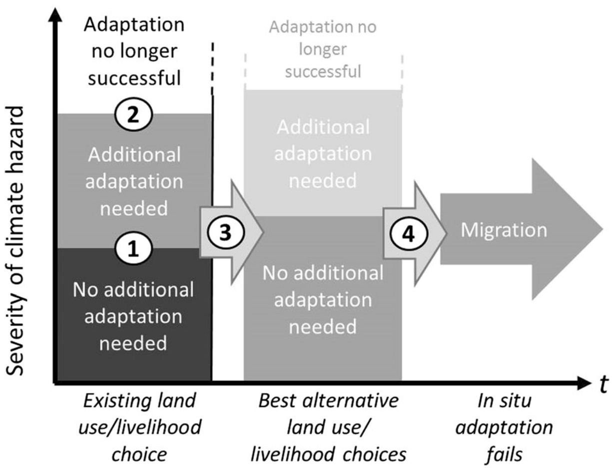

Fig. 1 Adaptation and thresholds in a hypothesized system

to various degrees by Canadian farmers since the 1930s (McLeman et al. 2010)). The ability to pursue such options in turn depends upon the farmer's financial means, technical skills and knowledge, and other limiting factors. Farmers may in some cases choose to diversify their farm operations, but in the 1930s, the response was more often intensification, to increase production in hopes of offsetting falling crop revenues (Nawrotzki and DeWaard 2016 note similar tensions between intensification and diversification among present-day farmers adapting to droughts in Mexico). Through these actions, the farmer attempts to push point 2 farther up the *Y* axis.

A third threshold identified by Adger et al. (2009) occurs when the nature of the human-environment relationship in a given situation undergoes a substantive change. Keeping to the same, aforementioned example, this would be a situation where conditions become so frequently hot and dry that wheat production is no longer economically viable.[1] In this situation, marked by point 3 on Fig. 1, the farmer ceases producing wheat and engages in some other form of land use and/or livelihood activity that is better adapted to changing climatic conditions. Precisely, what that would be depends upon a variety of factors beyond the productive capacity of the land, such as the farmer's financial resources, skills and expertise, access to technology, availability of off-farm employment in nearby areas, potential income from alternative land-use options given prevailing market conditions, and institutional support for farmers, among others (Smit and Skinner 2002). These alternative options are typically less financially lucrative than wheat farming; otherwise, the farmer would have already adopted them without the need for a climate stimulus. The crossing of threshold 3 is therefore an undesirable or disruptive transition from the farmer's perspective.

Adger et al. (2009) consequently arrive at a similar conclusion to Bardsley and Hugo (2010) that the long-term aim in an era of a rapidly changing climate should be to build inherently adaptive and flexible livelihood systems that can adjust to as wide a range of climatic hazards (and non-climatic risks as well) as possible. This conclusion dovetails with *resilience theory*, a branch of socioecological systems theory in which there is considerable preoccupation with ecological thresholds or tipping points. 'Resilience' refers to the capacity of a socioecological system to maintain its normal functioning without undergoing significant change when it experiences perturbations (Holling 1973; Gunderson 2000). An inherently resilient (or adaptive, and therefore less vulnerable) system is one where the threshold between a system's present state and a potentially undesirable one is distant or not easily crossed. Preston et al. (2013) describe this process in terms of 'safe' and 'unsafe' operation and rather than thinking of the threshold as a single tipping point, describe it as a transition zone or frontier. The authors use coral reefs as an example of an ecological system that is viable only within very narrow physical conditions in terms of temperature, water quality, water acidity, and salinity. Reefs therefore always exist close to an ecological frontier where even a small physical change (such as a small change in water temperature or acidity) can cause the reef to bleach and die (Pandolfi et al. 2011). Although Preston et al. (2013) do not explicitly pursue this example in terms of its human dimensions, a community of people that depends heavily on a coral reef for its livelihoods (such as fishing or

[1] General circulation models project that average temperatures in the Canadian Prairies will rise by several degrees in coming decades, especially winter temperatures, which would affect the timing and availability of snowmelt that contributes to soil moisture during the growing season (Romero-Lankao et al. 2014)

tourism) similarly operates very close to that physical frontier which, in a changing climate, is probably too close to be called 'safe'. The role of adaptation at the local scale is therefore to move the community's livelihoods away from the threshold where a failure of the reef triggers an immediate livelihood failure, while at a global scale, our collective aim should be to mitigate greenhouse gas emissions, since reef ecosystems themselves cannot be made more adaptive.

The threshold between in situ adaptation and migration

Migration scholarship on residential preferences holds that once an individual or household has established a place of permanent residence, future moves will not occur unless some adverse event occurs (such as a loss of employment) or irresistible opportunities emerge elsewhere; Wolpert (1966) and Speare (1974) refer to this as the 'threshold of dissatisfaction'. An equivalent to this residential dissatisfaction threshold exists in climate adaptation processes and is labelled as point 4 on Fig. 1. Observed by Meze-Hausken (2008) in her studies of drought adaptation in Ethiopia and further developed by Bardsley and Hugo (2010), this threshold occurs where in situ climate adaptations cease to be effective and migration is undertaken by one or more members of the household. Such migration may be temporary in nature, such as sending young adults to distant destinations in search of wage-earning opportunities (often referred to in scholarly literature as the 'new economics of labor migration' (Stark and Bloom 1985)) or it may be indefinite, with some or all household members relocating. From a scholarly perspective, threshold 4 is the analytical point at which the wider migration literature—with its consideration of economic processes, capital access, social networks, cultural norms, and other non-environmental influences—intersects with climate impacts and adaptation scholarship, with Hugo (1996, 2008, 2011) having contributed considerably to linking these often disconnected bodies of scholarship.

In my earlier example of 1930 drought adaptation on the Canadian Prairies, three concurrent economic factors helped push many drought-stricken farm households from threshold 2 to threshold 4 on Fig. 1. One was the collapse in commodity prices triggered by the stock market crash of 1929, which drastically reduced farm incomes (McLeman et al. 2010). Second, the collapse of many financial institutions meant that farmers had difficulty borrowing money to use for adaptation. Third, widespread unemployment meant that local off-farm employment was difficult to find. In the face of these combined climatic and economic challenges, thousands of farm families migrated out of the drought-affected areas to more northerly Aspen Parkland environments and to other Canadian provinces (Gilbert and McLeman 2010; Laforge and McLeman 2013; McLeman and Ploeger 2012).

It is important to note, however, that although many farm families migrated, many more did not. It was the same case in the US Dust Bowl of the southern Great Plains during the 1930s—hundreds of thousands migrated away, but many more stayed (Gregory 1989). This is a reminder that the decision to migrate or not in the face of a given climatic hazard is a function of the range of alternative adaptation options available to a given household, and these are in turn influenced by a wide range of cultural, demographic, economic, environmental, political, and social factors that operate across multiple scales from the local to the global (Foresight 2011). Migration can be an especially disruptive process, entailing financial, social, and emotional risks for migrants and for their families and social networks, and so it is often one of the last forms of adaptation to be attempted (Schade et al. 2015). We should also be reminded that, even where migration may be the best remaining adaptation option, a household may be unable to migrate due to inadequate financial resources, poor health, lack of social networks, and other factors that make migration possible. There are cases where households reach threshold 4, where in situ adaptation is no longer feasible, but remain immobile and trapped due to circumstances beyond their control (Black et al. 2013). In short, a climate hazard that leads one household to migrate may not produce the same outcome for another.

Some additional nuance is needed when discussing climate migration thresholds in regions where seasonal labor migration and/or pastoralism are common livelihood strategies, such as areas with highly seasonal precipitation regimes in South and Southeast Asia and Sub-Saharan Africa (Warner and Afifi 2014). In such cases, temporary migration *is* the adaptation that allows the household to maintain its permanent residence in situ in an area with a variable climate. The fourth threshold is thus reached not when migration takes place—for it is already occurring and is the 'normal' situation—but when a substantive change in migration timing, destination, and/or participation rate occurs because 'normal' migration-based adaptation strategies are inadequate. In such cases, the fourth threshold may be followed by a number of possible outcomes including:

- a significant change in the destination or timing of temporary migration
- a switch to a less mobile type of livelihood
- a switch from temporary migration to permanent relocation

For example, in Bangladesh, where flooding during the monsoon season is a regular phenomenon, rural people will often migrate for short distances until flood waters recede; many will also migrate a second time during the period between rice harvests, known as *monga*, when food and income is scarce in the countryside (Ahamad et al. 2011; Khandker et al. 2012). Although it is flood and climate related, this temporary, circular migration is commonplace and normal; it does not reflect a crossing of the fourth threshold. Rather, it is irregularly occurring climate events such as droughts, extreme heat events, and cyclones that lead to disruptive changes in migration patterns, such as influxes of rural migrants to cities and families relocating within rural areas or to neighbouring India (Gray and Mueller 2012; Mallick and Vogt 2012; Saha 2016).

The threshold between linear and non-linear migration under climate change: differential effects of climate hazards

The quote from Bardsley and Hugo (2010) that began this article asked whether climate change will lead to non-linear changes in regional and global migration patterns. Rephrased, it asks if there is a fifth threshold, where the aggregated outcomes of individual adaptation decisions described in Fig. 1 generate wide-scale changes in migration participation rates, patterns, and/or behavior. As the following paragraphs show, such a threshold certainly exists at local scales; whether it will also emerge at regional and global scales depends on several factors.

One key consideration is the nature of the climate hazard in question. Rapid-onset events such as hurricanes generate temporary non-linearity in migration patterns in affected areas, particularly given their potential to damage housing and livelihoods. For example, migration patterns in New Orleans following 2005's Hurricane Katrina have been well studied and show a 'churning' pattern as people from various social, economic, and cultural groups returned, did not return, and/or moved to New Orleans for the first time according to a wide range of factors such as damage to housing stocks, job opportunities, place attachment, and social networks, among others (Fussell et al. 2010, DeWaard et al. 2016). As can be seen in Fig. 2, the city's population has not returned to pre-Katrina levels. In another example, Hurricane Mitch in 1999 was followed by surges in labor migration from affected areas in Honduras, Guatemala, and Nicaragua to neighbouring countries, Costa Rica and Belize, as well as longer-distance migration of young adults to the USA (Fig. 3) (McLeman 2014). As with Katrina, damage to housing stocks was a key push factor, with existing social networks facilitating movement to labor migration destinations. The large pulse in post-Mitch migration was likely compounded by the minimal financial assistance affected households received from governments and relief agencies (Morris and Wodon 2003). Should there be an increase in the frequency, intensity, and/or geographic distribution of sudden-onset events—almost certain in some regions, less certain in others (IPCC 2013)—a corresponding increase in churning, pulse-like migration events should be expected.

By contrast, progressive, slow-emerging climatic risks such as droughts generally allow more time for recognition of the potential impacts and implementation of adaptation responses by affected individuals and households, as well as by higher-level actors and institutions. The time lag between the third and fourth thresholds is typically much longer than in the case of sudden-onset events. The 1930 'Dust Bowl' migration of over a hundred thousand people from rural Oklahoma—described by one contemporary observer as an 'exodus' (Duncan 1935)—accelerated only after multiple

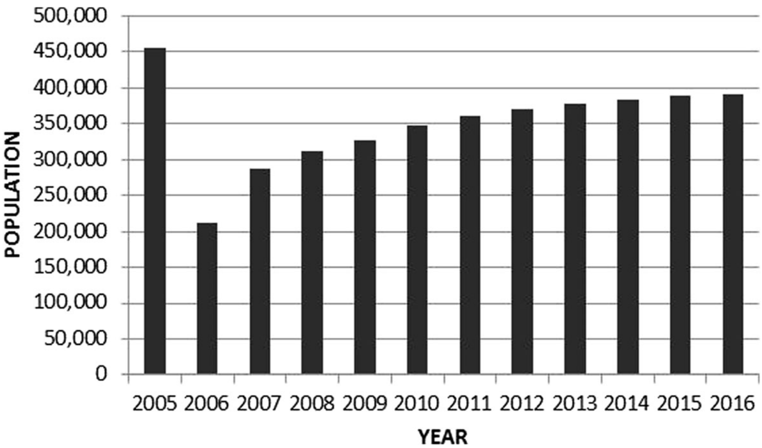

Fig. 2 Population of city of New Orleans (Orleans Parish), before and after Hurricane Katrina, 2005. Data source: US Census Bureau

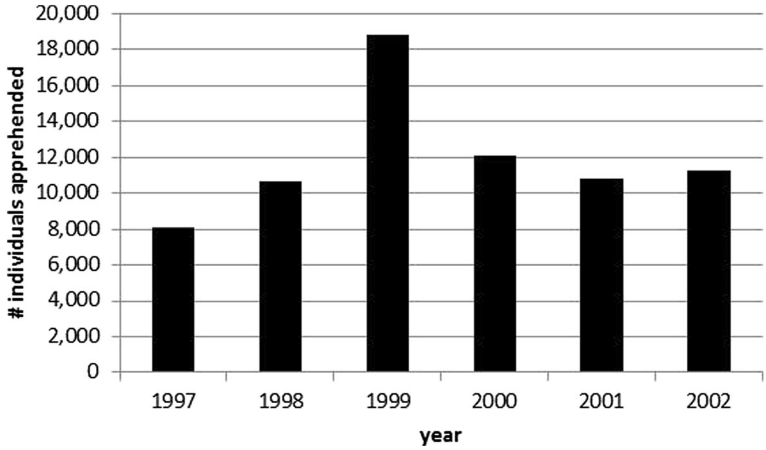

Fig. 3 Honduran nationals apprehended entering the USA via Mexico without authorization, before and after Hurricane Mitch (October 1998). Data source: US INS statistical yearbooks

years of poor harvests due to droughts and, in some areas, floods (McLeman 2006; McLeman et al. 2008). Recent research by Nawrotzki et al. (2017) found that hot, dry conditions in rural Mexico cause incremental increases in migration in affected areas, but only after nearly 3 years of such conditions does a non-linear increase emerge. Earlier, it was noted that in Bangladesh, flooding, despite being a sudden-onset event, is so common it rarely upsets normal migration patterns. This suggests that over time, in situ adaptive capacity becomes geared toward the most common climatic hazards, regardless of rate of onset. Less common climate events thus become the more disruptive ones, and recent research by Murphy et al. (2017) on the historical impacts of infrequent droughts in Ireland is consistent with this.

As shown by the examples above—of Hurricanes Mitch and Katrina, of droughts in North America and Africa, and of floods in Bangladesh—and by many other examples not described here, non-linear, climate-related migration events already occur at local and sub-regional scales and should be expected to continue to do so in the future. In terms of Bardsley and Hugo's question of whether anthropogenic climate change will generate non-linear migration events on a much larger scale, one would need to go back to the Medieval Warm Period to find historical analogues (Behringer 2010; Lamb 1982; McLeman 2014). Global migration patterns have certainly undergone extraordinary changes in the past century that could readily be characterized as global and non-linear—think of conflict-related displacements in the early twentieth century and the rapid urbanization that continues in many parts of the world—but these have not been driven by climate.

Looking to the future impacts of anthropogenic climate change, the most likely physical outcomes in the next 25 to 50 years represent, for the most part, exacerbations of existing climate risks that affect populations at local or regional scales, such as increased frequency or severity of seasonal dryness and droughts, and greater risks of flood hazards and extreme storms in areas already prone to experiencing such phenomena (IPCC 2013, 2014). Mean sea-level rise (MSLR), which will eventually require large-scale relocation of coastal populations around the globe, is currently taking the shape of a very slow-onset hazard, advancing at a rate of a few millimeters per year (Carson et al. 2016; Dieng et al. 2017; IPCC 2014). If this rate of increase remains stable, it will not be until the late twenty-first century or early twenty-second century that large numbers of people living low-lying coastal areas will be affected. This allows, at least in principle, considerable time for human populations to (1) implement in situ adaptation strategies to avoid the need for relocating people from densely populated coastal settlements and (2) more importantly, to control the greenhouse gas emissions that create the threat. However—and this is an important 'however'—should the global community do nothing in the next 20 to 30 years to curb current greenhouse gas emissions, rapid atmospheric warming could generate meltwaters from Antarctica and Greenland that raise mean sea levels by up to 1 m by 2100 (DeConto and Pollard 2016). Other physical manifestations of climate change may also become non-linear, leading to 'surprises' in the behavior of ecological systems (Jordan et al. 2013). In such a case, it becomes increasingly likely that global migration patterns will respond in non-linear fashion to climate change.

Thresholds in group migration dynamics: how non-linear migration flows are initiated, grow, and ebb

Migration is the outcome of a binary decision made at the household level: to move or not (Speare 1974). However, the movement of large numbers of people is not simply an aggregation of individual household decisions made independently of one another. Every decision to migrate alters—sometimes slightly, sometimes not so slightly—the demographic and socioeconomic configuration of the sending and destination areas, which can in turn influence the decisions of other people who may be contemplating migration. Recognition of this dynamic by researchers in the 1970s and 1980s—including Graeme Hugo through his empirical research in Indonesia (1978, 1982)—gave rise to threshold and equilibrium models of migration (and of other forms of social behavior in binary-choice situations) that are relevant to understanding thresholds. For example, Granovetter (1978) explored the question of how many people within a given group or population must do something before it encourages others to follow suit. He found that such tipping points are highly situation-specific (a recurrent theme in the study of thresholds more generally (Bardsley and Hugo 2010)) and that individuals' perceptions and assessments of the potential costs and benefits of a particular decision can be highly subjective, are often factually inaccurate, and complicate the ability of the outside observer to anticipate particular outcomes.

In modelling binary decision-making behavior, Granovetter (1978) assumed that people's preferences for choosing one option over another fall in a normal distribution around a mean—some people strongly preferring option 1, others feeling strongly about option 2, and most falling somewhere in between. In his analysis, a critical factor is the standard deviation in preferences among the population in question; even a slight change in it can trigger a radical change in group behavior when people are forced to make decisions. This was further illustrated by behavioral economist Thomas Schelling (1978), who explored observations made previously by Grodzins (1958) that in many American cities, it was easy to find neighbourhoods and streets where residents were mostly all white or all black, but difficult to find residential areas with a balanced mix of the two racial backgrounds. Further, in the few neighbourhoods that did display a mix of racial backgrounds, that situation often did not endure, and within a short period of time, members of one group moved out and were replaced by additional residents of the newly dominant group. I will elaborate on Schelling's (1978) work in the next few paragraphs, not because I wish to analyze racial interactions at the neighbourhood level—for these have been shown to be much more complicated in subsequent research—but because of how Schilling was able to illustrate using simple game theory-based mathematical techniques how the decision of a few individuals to move can trigger non-linear flows of population.

Schelling (1978) began with a modest assumption that most Americans feel most comfortable living in residential areas where they are not a racial minority and would be satisfied with a 50:50 ratio of people of their own racial group versus other groups. Within any group, there will be a small percentage who are indifferent to the racial characteristics of their neighbours, a small percentage for whom racial characteristics are the most important criterion in choosing where to live, and a majority who fall somewhere between those two extremes (i.e. there is a normal distribution curve of preferences). This assumption is illustrated in Fig. 4, which shows cumulative preference curves reflecting a hypothesized willingness of blacks and whites to live in proximity to one another.

Note that Fig. 4 does not reflect the actual distribution of people living in the neighbourhood, just the average preferences of people in both groups. So long as the mean of the actual distribution falls within the shaded area where the two curves overlap, most people living in the neighbourhood will be mostly happy with its racial composition. However, even with an exact 50:50 ratio of blacks to whites, a small number of residents will be less than fully happy with the neighbourhood and some quite dissatisfied. If the actual ratio is even slightly different than 50:50—say, a ratio of 55:45 blacks to whites—a greater number of white residents than black residents would be dissatisfied with the racial composition of the neighbourhood. In such a situation,

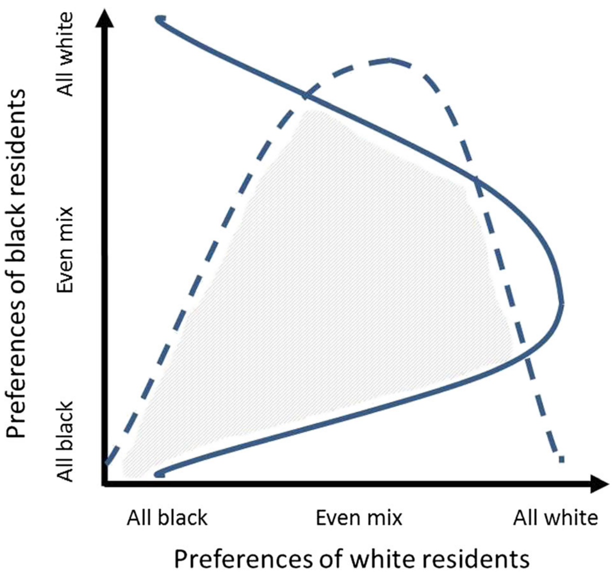

Fig. 4 Hypothetical residential preference curves based on Schelling (1978)

should a white family decide to move out of the neighbourhood (the reason for the move is irrelevant), a black family is more likely to move into the vacated house than is a white family. If that happens, the ratio of blacks to whites in the neighbourhood is further skewed, and among the remaining white residents, there will be additional individuals who were once satisfied with the racial composition of the neighbourhood, but are no longer so. Such individuals may therefore begin contemplating a move to another neighbourhood and perhaps may discuss their concerns with their neighbours. Very quickly, a perception—rightly or wrongly—may spread among white residents that the neighbourhood will soon be dominated by blacks. Once this happens, even white residents who are accepting of black neighbours but dislike the idea of being a minority may contemplate a move elsewhere. Each additional departure generates a new vacancy that is increasingly more likely to be filled by a black family, and the process reinforces itself until most residents are black.

I will reiterate: the racial dynamics of American cities are far more complicated than being a simple question of people's preferences to live near people of other races. What I just described is simply a game theory representation of the process, but it highlights two points relevant to understanding climate-adaptive migration. First, if we assume that people do not have homogeneous preferences (a very reasonable assumption), even modest changes in the number of people moving in or out of a given location will have consequences on the behavior of others (especially for those whose friends or relations are the ones moving). Second, perceptions of the future matter, and, when combined with differential preferences, can generate non-linear movements of people very quickly. Common examples of such processes in action range from gentrification of once-poor urban neighbourhoods to processes of settlement abandonment in the context of environmental degradation (see McLeman 2011 for several examples of the latter).

The self-reinforcing effects of migration flows, once started, have long been recognized by migration scholars (Mabogunje 1970; Massey 1990). However, Massey and Espinosa (1997) and de Haas 2010 note that such processes are not universal; sometimes migration stimulates additional migration by others, but other times it does not. Further, migration participation tends not to expand or continue indefinitely, but eventually ebbs (as seen, for example, in Figs. 2 and 3 above). That is, non-linearity eventually gives way to linearity.

De Haas (2010) suggests that changes in the marginal costs and benefits of migration over time may be responsible for surges and ebbs in migration rates. The first migrants to a new destination often incur disproportionately high economic and social costs. In some cases, they do not experience economic success, but in others, they may profit from being a new or scarce quantity on labor markets in the destination area. Either way, news of their experience will travel back to the sending community, where it will be shared and discussed among people with limited knowledge of the destination. Stories of migration success will stimulate a non-linear increase in additional migrants, and the cost of migration declines as new migrants draw upon the information and social capital provided by those who went before. Established migrants often remit money home, which may encourage (or alternatively obviate the need for) other family members to migrate. The newfound remittance wealth creates a visual incentive for other families to try their luck at migration. However, as more migrants arrive, the supply of labor may overtake demand, and income opportunities consequently become scarcer, causing migration rates to slow.

In other words, the relationship between the financial, psychological, and social cost/benefits of migration fluctuates over time. Migration flows will rapidly slow should the benefit-to-cost ratio drop beyond a certain threshold (de Haas (2010) suggests it is a 4:1 or 5:1 ratio of financial benefits versus costs). Granovetter (1978) and Epstein (2008) emphasize the importance of weak social ties, such as friends and acquaintances, in helping make migration behavior self-reinforcing in its early stages and of external effects (such as labor market changes or the responses of the receiving population to new migrants) for causing migration to slow or cease.

Community assets and linear/non-linear migration tipping points

Incremental changes in population can cause changes in the provision or availability of key services and infrastructure that make a community desirable or viable, and these can in turn suddenly tip population change from incremental to non-linear in nature. I have observed this relationship firsthand in my research on climate adaptation in rural communities in eastern Ontario, Canada, findings from which have appeared in this journal and elsewhere (McLeman 2010; McLeman et al. 2011; Sander-Regier et al. 2010; McLeman and Ford 2013; Keizer et al. 2015). The experiences of two villages in the region illustrate the reciprocal relationship between population change and infrastructure, the presence of tipping points within that relationship, and the implications for climate adaptation at the community and household level.

The village of Denbigh, Ontario, with a population of 700, is situated in relatively remote upland area 120 km north of the nearest urban centre. After years of declining enrollment, Denbigh's elementary school was closed in 2006, and the remaining children were bussed to a school 30 minutes away. This immediately made Denbigh less attractive to young families, who began relocating elsewhere, and had negative effects on property values. The school closure was followed by business closures and concerns that the health clinic, library, and ambulance station would soon follow. Recognizing their community was at a tipping point, residents came together and successfully raised funds to purchase the school building and convert it to a modern nursing station and community centre. The community's long-term prospects remain tenuous; although a descent into rapid population decline has been temporarily forestalled, the aging population and lack of young families moving in means the population will dwindle over the next two decades.

The village of Spencerville, in a farming area 190 km southeast of Denbigh, learned in 2007 its one and only bank branch was going to be shut down. Farming communities tend to have short- and long-term credit needs distinctive from those of urban populations, and this impending loss of retail banking services was perceived by local residents and business owners as being a critical tipping point to be avoided. A community task force was organized that successfully persuaded a smaller, rival financial institution to open a new branch in the village.

What do the examples of Denbigh and Spencerville have to do with climate adaptation and migration? The regional climate in recent decades has trended toward shorter, milder, and less snowy winters, presenting new challenges and opportunities for households, communities, and local governments (McLeman 2010; Sander-Regier et al. 2010). The ability to avoid negative climate impacts and take advantage of new opportunities is, however, contingent upon the communities' having stable population bases and the key infrastructure and services to keep them viable. The loss of a school or a bank or a clinic can have a non-linear impact not just on population numbers, but on the community's adaptive capacity. Similar relationships between rural population change, key community assets, and climate adaptation have been observed elsewhere in Canada (McLeman et al. 2011) and in other countries as well (Kiem and Asutin 2013; Nelson et al. 2010). Although my examples here focus on rural population decline, in fast-growing urban centres, the inability of infrastructure or key assets to keep pace with rapid population growth may be an impediment to building climate adaptation capacity (Birkmann et al. 2010; Garschagen and Romero-Lankao 2015).

Key community members and tipping points

In the two examples given in the previous section, community members recognized an impending threat to the well-being of their village, mobilized, took action, and moved the community away from a tipping point that could stimulate population decline. Something I did not mention is that not all residents of the two communities in question participated; in both cases, it was a small group of individuals with particular skillsets and a very strong 'sense of place' that drove the initiatives. Had even a small number of these individuals been disinclined to act, or perhaps decided to simply leave town as soon as possible, the outcomes might have been dramatically different. The implication is that the presence or absence of certain types of individuals, and the actions they take, can have a disproportionate influence on adaptation and migration processes within a given population. This features prominently in Malcolm Gladwell's bestselling book, *The Tipping Point*: *How little things can make a big difference*. In it, Gladwell (2000) observed that:

(1) Certain individuals are more important than others in terms of their ability to stimulate social changes, usually because they are part of extensive social networks, often in turn because they actively cultivate these networks. When one or more of these individuals decides upon a course of action, others are likely to follow.
(2) Many non-linear outcomes arise because their initiators have acted on intuition rather than adhering to the customary rules of social behavior.
(3) Although people like to think of themselves as autonomous decision-makers, they will often, with little critical thinking, act upon external visual cues from their surroundings or things heard in conversation with others. When this prompts them to suspect change is happening around them, they may very rapidly modify their own behavior.

These three observations suggest a need for greater attention to how key individuals within a given population perceive climate-related risks and the processes through which they then choose to migrate (or not) given those perceptions. While there has been research in recent decades on the role of perception in climate adaptation and environmental decision-making in general (Lee et al. 2015; Semenza et al. 2008; Weber 2010), far less work has been done on the role of perception in climate-related migration decision-making specifically.

In one of the few latter such studies available, Koubi et al. (2016) surveyed individuals in five developing countries and found that perceiving oneself as being at risk of harm from (or indeed, actually experiencing) a sudden-onset event, such as flooding or extreme storms, creates a relatively high potential for migration. When such migration does occur, it does so in a sharp, non-linear fashion. By contrast, the authors found that environmental risks perceived as being slow-onset in nature, such as droughts or soil erosion, are unlikely to stimulate immediate thoughts of migration. This is consistent with studies of populations living on the low-lying Pacific atolls at risk of future inundation due to sea-level rise, which find that while most people are aware of such risks, these do not figure into current migration decisions (Mortreux and Barnett 2009; Shen and Gemenne 2011). While studies such as these are a useful beginning, they still focus primarily on the overall pattern of migration outcomes. Attention to more individualistic behavior in the context of climate-related migration decisions would be very useful and may require collaboration with disciplines like behavioral psychology that have heretofore had minimal engagement with the field of population and environment.

Summing up: thresholds, why they matter, and next steps for researchers

This article has identified a number of thresholds that can potentially be present in processes of climate adaptation and migration. These include:

(1) A need for adaptation arises
(2) Adaptations cease to be effective
(3) Land use or livelihoods undergo fundamental change
(4) Migration replaces in situ adaptation
(5) Migration becomes non-linear
(6) Non-linear migration ceases

Much of what I have laid out in this article builds upon and refines the work of Professor Graeme Hugo and his many research collaborators. As Bardsley and Hugo (2010) observed previously in this journal, thresholds are highly context-specific and vary according to the characteristics of the natural and human systems at a given place and time. The characteristics of the natural system, the scale of climate-related changes to it, and the rate of onset of such changes all help shape the rate of progression through the aforementioned thresholds. The characteristics of human systems also help shape the rate of progression through the first four thresholds and the likelihood of non-linear migration participation emerging. Once population movements occur, feedback effects develop that reinforce patterns of behavior, depending on people's preferences and perceptions. Particular types of individuals within a given population may have a disproportionate influence on whether thresholds are crossed (or not). The loss of key services and infrastructure can also reinforce population trends and potentially act as tipping points between incremental and non-linear migration behavior.

The phrase 'context-specific' should not be interpreted as meaning that thresholds in climate adaptation and migration are unknowable beyond a conceptual sense, or that they cannot be identified before they are encountered. On the contrary, there are numerous well-established methodologies for identifying vulnerability and adaptation needs at local and regional levels (Füssel 2007; van Aalst et al. 2008). Although most examples of such research focus on adaptation needs and limits without explicitly taking into account the specific outcome of migration, it is a relatively small methodological 'next step' to incorporate the identification of potential migration futures and tipping points into such studies. Future research will hopefully do so. There is also a continually growing volume of field-based qualitative case studies and retrospective quantitative studies that use panel data to understand how particular types of climate phenomena influence migration behavior, the findings from which are already being incorporated by researchers using geospatial modelling and agent-based modelling techniques to project future climate-related migration at national and regional scales (de Sherbinin 2014; Kniveton et al. 2011; Smith 2014). The better we understand the presence and functioning of thresholds, the better and more accurate these models will be.

As our methodological techniques become increasingly refined in coming years and as researchers begin embracing mixed-method approaches, we will be able to more precisely anticipate worrisome thresholds and generate proactive responses. There will always be the potential for surprises in future climate-related migration and unexpected tipping points, given that anthropogenic greenhouse gas emissions are forcing the climate to behave in ways we have not previously experienced. However, given the sheer volume of research on climate migration that is coming available with each passing year, I would suggest that our ability to anticipate and predict climate-related migration at all scales, from local to global, will only strengthen.

Beyond the obvious methodological interests in better identifying and understanding thresholds in climate migration, there are practical ones for those who must plan for and organize responses to large-scale population movements. Instead of a general summary of why this is so, the following specific example captures precisely what is at stake. In June 2016, a workshop[2] was held in Portland, Oregon, that brought together demographers and urban planning officials from Portland and Seattle, two of the fastest-growing metropolitan areas in the USA. The aim was to identify how the impacts of climate change would affect future migration flows to these cities, which receive large numbers of migrants from water-scarce states in the American southwest that climate change will make increasingly dry. Population projections are important tools for urban planners, who must budget and plan decades in advance for critical municipal infrastructure such as roads, water, wastewater treatment, and electrical supplies. Incremental population growth is something planners are comfortable dealing with, but non-linear changes in population can undo their best made plans. If a sudden surge of people arriving from the southwestern USA is something that could happen 20 or 30 years from now because of climate change, urban planners in Seattle and Portland must make contingency plans today. Specifically, they need to know how and when such a sudden change in migration patterns might plausibly occur and then assess the extent to which the infrastructure they build today could cope with such a future influx and how much extra money would need to be invested to make sure that it could. In other words,

[2] For a detailed agenda, see https://cig.uw.edu/wp-content/uploads/sites/2/2014/11/Symposium-agenda.pdf.

they need information about climate migration thresholds in the southwestern USA to avoid critical thresholds in their cities' ability to absorb new migrants.

The aforementioned workshop is just one example of the practical reasons why further research is needed to refine our understanding of thresholds and tipping points embedded in climate adaptation and migration processes, and to strive to continually improve our ability to identify them proactively at global, regional, and local scales. Policy- and decision-makers are increasingly asking such questions of researchers for a wide range of applications, and such demands will only grow. More than most people, Professor Graeme Hugo was highly attuned to how academic researchers in general, and scholars in the field of population and environment in particular, could support real-life decisions. In the 1990s, in the midst of breathless warnings of hundreds of millions of environmental refugees to come in the mid-2000s, Hugo (1996) was writing theoretically grounded, empirically sound analyses of the links between environment and migration. He never lost interest in the subject and through continued efforts showed that environmental migration is highly complex but understandable if you are systematic in your approach (Hugo 2011). It is therefore no surprise that in recent years, his expertise on environmental migration was sought out by national governments and multilateral organizations like the World Bank, the Asian Development Bank, and the International Organization for Migration. In attempting to further develop the research he and Douglas Bardsley did on the topic of thresholds in environmental migration, I hope that I am in a small way helping to honor and continue his legacy.

References

Adger, W. N., Lorenzoni, I., & O'Brien, K. L. (2009). Adaptation now. In W. N. Adger, I. Lorenzoni, & K. L. O'Brien (Eds.), *Adapting to climate change: thresholds, values, governance* (pp. 1–22). Cambridge: Cambridge University Press.

Ahamad, M. G., et al. (2011). Seasonal unemployment and voluntary out-migration from Northern Bangladesh. *Mod Econ, 2*, 174–179.

Asian Development Bank. (2012). *Addressing climate change and migration in Asia and the Pacific*. Manila: Asian Development Bank.

Bardsley, D. K., & Hugo, G. J. (2010). Migration and climate change: examining thresholds of change to guide effective adaptation decision-making. *Popul Environ, 32*(2–3), 238–262.

Behringer, W. (2010). *A cultural history of climate*. Malden: Polity Press.

Birkmann, J., et al. (2010). Adaptive urban governance: new challenges for the second generation of urban adaptation strategies to climate change. *Sustain Sci, 5*(2), 185–206.

Black, R. (2011). Climate change: migration as adaptation. *Nature, 478*, 447–449.

Black, R., et al. (2011). The effect of environmental change on human migration. *Glob Environ Chang, 21*(S1), S3–S11.

Black, R., et al. (2013). Migration, immobility and displacement outcomes following extreme events. *Environ Sci Policy, 27*(S1), S32–S43.

Carson, M., et al. (2016). Coastal sea level changes, observed and projected during the 20th and 21st century. *Clim Chang, 134*(1), 269–281.

Castles, S., de Haas, H., & Miller, M. J. (2013). *The age of migration: international population movements in the modern world* (5th ed.). New York: Palgrave Macmillan.

de Haas, H. (2010). The internal dynamics of migration processes: a theoretical inquiry. *J Ethn Migr Stud, 36*(10), 1587–1617.

de Sherbinin, A. (2014). Climate change hotspots mapping: what have we learned? *Clim Chang, 123*(1), 23–37.

DeConto, R. M., & Pollard, D. (2016). Contribution of Antarctica to past and future sea-level rise. *Nature, 531*, 591–597.

DeWaard, J., Curtis, K. J., & Fussell, E. (2016). Population recovery in New Orleans after Hurricane Katrina: exploring the potential role of stage migration in migration systems. *Popul Environ, 37*(4), 449–463.

Dieng, H. B., et al. (2017). New estimate of the current rate of sea level rise from a sea level budget approach. *Geophys Res Lett, 44*(8), 3744–3751.

Duncan, O. D. (1935). *Population trends in Oklahoma*. Stillwater: Oklahoma Agricultural Experiment Station.

Epstein, G. S. (2008). Herd and network effects in migration decision-making. *J Ethn Migr Stud, 34*(4), 567–583.

Fawcett, J. (1989). Networks, linkages, and migration systems. *Int Migr Rev, 23*(3), 671–680.

Foresight: migration and global environmental change. (2011). *Final project report*. London: Government Office for Science.

Füssel, H.-M. (2007). Adaptation planning for climate change: concepts, assessment approaches, and key lessons. *Sustain Sci, 2*(2), 265–275.

Fussell, E., Sastry, N., & VanLandingham, M. (2010). Race, socioeconomic status, and return migration to New Orleans after Hurricane Katrina. *Popul Environ, 31*(1–3), 20–42.

Garschagen, M., & Romero-Lankao, P. (2015). Exploring the relationships between urbanization trends and climate change vulnerability. *Clim Chang, 133*(1), 37–52.

Gilbert, G., & McLeman, R. (2010). Household access to capital and its effects on drought adaptation and migration: a case study of rural Alberta in the 1930s. *Popul Environ, 32*(1), 3–26.

Gladwell, M. (2000). *The tipping point: how little things can make a big difference*. New York: Little, Brown and Company.

Granovetter, M. (1978). Threshold models of collective behavior. *Am J Sociol, 83*(6), 1420–1443.

Gray, C. L., & Mueller, V. (2012). Natural disasters and population mobility in Bangladesh. *Proc Natl Acad Sci, 109*(16), 6000–6005.

Gregory, J. N. (1989). *American exodus: the dust bowl migration and Okie culture in California*. New York: Oxford University Press.

Grodzins, M. (1958). *The metropolitan area as a racial problem*. Pittsburgh: University of Pittsburgh Press.

Gunderson, L. (2000). Ecological resilience—in theory and application. *Annu Rev Ecol Syst, 31*, 425–439.

Holling, C. S. (1973). Resilience and stability of ecological systems. *Annu Rev Ecol Syst, 4*, 1–23.

Hugo, G. (1996). Environmental concerns and international migration. *Int Migr Rev, 30*(1), 105.

Hugo, G. (1998). The demographic underpinnings of current and future international migration in Asia. *Asia and Pacific Migration Journal, 7*(1), 1–25.

Hugo, G. (2005). The new international migration in Asia. *Asian Population Studies, 1*(1), 93–120.

Hugo, G. (2008). *Migration, development and environment*. Geneva: International Organization for Migration.

Hugo, G. (2011). Future demographic change and its interactions with migration and climate change. *Glob Environ Chang, 21*(SI), S21–S33.

Hugo, G., & Bardsley, D. K. (2014). Migration and environmental change in Asia. In E. Piguet & F. Laczko (Eds.), *Migration and environmental change in Asia* (pp. 21–48). Dordrecht: Springer.

Hugo, G., Bardsley, D. K., Tan, Y., Sharma, V., Williams, M., & Bedford, R. (2009). *Climate change and migration in the Asia-Pacific region. Unpublished report to the Asian Development Bank*. Manila: Asian Development Bank.

IPCC (2013). *Climate Change 2013: The Physical Science Basis*. In T. F. Stocker, D. Qin, G.-K. Plattner, M. Tignor, S. K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P. M. Midgley (Eds.), *Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. United Kingdom and New York, NY, USA: Cambridge University Press, Cambridge.

IPCC (2014). Summary for policymakers. In C. B. Field, V. R. Barros, D. J. Dokken, K. J. Mach, M. D. Mastrandrea, T. E. Bilir, M. Chatterjee, K. L. Ebi, Y. O. Estrada, R. C. Genova, B. Girma, E. S. Kissel, A. N. Levy, S. MacCracken, P. R. Mastrandrea, and L. L. White (Eds.), *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* (pp. 1–32). United Kingdom and New York, NY, USA: Cambridge University Press, Cambridge.

Jordan, A., et al. (2013). Going beyond two degrees? The risks and opportunities of alternative options. *Clim Pol, 13*(6), 751–769.

Keizer, P. S., Gajewski, K., & McLeman, R. (2015). Forest dynamics in relation to multi-decadal late-Holocene climatic variability, eastern Ontario, Canada. *Rev Palaeobot Palynol, 219*, 106–115.

Khandker, S. R., Khalily, M. A. B., & Samad, H. A. (2012). Seasonal migration to mitigate income seasonality: evidence from Bangladesh. *J Dev Stud, 48*(8), 1063–1083.

Kiem, A. S., & Asutin, E. K. (2013). Drought and the future of rural communities: opportunities and challenges for climate change adaptation in regional Victoria, Australia. *Glob Environ Chang, 23*(5), 1307–1316.

King, R., & Skeldon, R. (2010). “Mind the gap!” integrating approaches to internal and international migration. *J Ethn Migr Stud, 36*(10), 1619–1646.
Kniveton, D., Smith, C., & Wood, S. (2011). Agent-based model simulations of future changes in migration flows for Burkina Faso. *Glob Environ Chang, 21*(S1), S34–S40.
Koubi, V., Spilker, G., Schaffer, L., & Böhmelt, T. (2016). The role of environmental perceptions in migration decision-making: evidence from both migrants and non-migrants in five developing countries. *Population and Environment, 38*(2), 134–163.
Laforge, J., & McLeman, R. (2013). Social capital and drought-migrant integration in 1930s Saskatchewan. *Can Geogr, 57*(4), 488–505.
Lamb, H. H. (1982). *Climate history and the modern world*. London: Methuen.
Lee, T. M., et al. (2015). Predictors of public climate change awareness and risk perception around the world. *Nat Clim Chang, 5*, 1014–1020.
Mabogunje, A. (1970). Systems approach to a theory of rural-urban migration. *Geogr Anal, 2*, 1–18.
Mallick, B., & Vogt, J. (2012). Cyclone, coastal society and migration: empirical evidence from Bangladesh. *Int Dev Plan Rev, 34*(3), 217–240.
Massey, D. S. (1990). Social structure, household strategies, and the cumulative causation of migration. *Population Index, 56*, 3–26.
Massey, D. S., & Espinosa, K. E. (1997). What’s driving Mexico-US migration? A theoretical, empirical and policy analysis. *Am J Sociol, 102*(4), 939–999.
McLeman, R. (2006). Migration out of 1930s rural eastern Oklahoma: insights for climate change research. *Great Plains Quarterly, 26*(1), 27–40.
McLeman, R. (2010). Impacts of population change on vulnerability and the capacity to adapt to climate change and variability: a typology based on lessons from a hard country. *Popul Environ, 31*(5), 286–316.
McLeman, R. (2011). Settlement abandonment in the context of global environmental change. *Glob Environ Chang, 21*(S1), S108–S120.
McLeman, R. (2014). *Climate and human migration: past experiences, future challenges*. New York: Cambridge University Press.
McLeman, R., & Ford, J. D. (2013). How demographic change and migration influence community-level adaptation to climate change: examples from rural eastern Ontario and Nunavut, Canada. In T. Faist & J. Schade (Eds.), *Disentangling migration and climate change: methodologies, political discourses, and human rights* (pp. 55–79). Berlin: Springer.
McLeman, R., & Ploeger, S. K. (2012). Soil and its influence on rural drought migration: insights from depression-era southwestern Saskatchewan, Canada. *Popul Environ, 33*(4), 304–332.
McLeman, R., & Smit, B. (2006). Migration as an adaptation to climate change. *Clim Chang, 76*(1–2), 31–53.
McLeman, R., et al. (2008). Drought adaptation in rural eastern Oklahoma in the 1930s: lessons for climate change adaptation research. *Mitig Adapt Strateg Glob Chang, 13*(4), 379–400.
McLeman, R., et al. (2010). GIS-based modeling of drought and historical population change on the Canadian Prairies. *J Hist Geogr, 36*, 43–55.
McLeman, R., et al. (2011). Opportunities and barriers for adaptation in Canadian rural and resource-based communities. In J. Ford & L. B. Ford (Eds.), *Climate change adaptation in developed nations* (pp. 449–460). Dordrecht: Springer.
Meze-Hausken, E. (2008). On the (im-)possibilities of defining human climate thresholds. *Clim Chang, 89*(3–4), 299–324.
Morris, S. S., & Wodon, Q. (2003). The allocation of natural disaster relief funds: Hurricane Mitch in Honduras. *World Dev, 31*(7), 1279–1289.
Mortreux, C., & Barnett, J. (2009). Climate change, migration and adaptation in Funafuti, Tuvalu. *Glob Environ Chang, 19*(1), 105–112.
Murphy, C., Noone, S., Duffy, C., Broderick, C., Matthews, T., & Wilby, R. (2017). Irish droughts in newspaper archives: Rediscovering forgotten hazards. *Weather, 72*(6), 151–155.
Nawrotzki, R., & DeWaard, J. (2016). Climate shocks and the timing of migration from Mexico. *Popul Environ, 38*(1), 72–100.
Nawrotzki, R. J., et al. (2017). Climate shocks and rural-urban migration in Mexico: Exploring nonlinearities and thresholds. *Clim Chang, 140*(2), 243–258.
Nelson, R., et al. (2010). The vulnerability of Australian rural communities to climate variability and change: part II—integrating impacts with adaptive capacity. *Environ Sci Pol, 13*(1), 8–17.
Pandolfi, J. M., et al. (2011). Projecting coral reef futures under global warming and ocean acidification. *Science, 333*(6041), 418–422.
Preston, B. L., Dow, K., & Berkhout, F. (2013). The climate adaptation frontier. *Sustainability, 5*(3), 1011–1035.

Romero-Lankao, P., et al. (2014). North America. In V. R. Barros et al. (Eds.), *Climate change 2014: Impacts, adaptation, and vulnerability. Part B: regional aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* (pp. 1439–1498). Cambridge: Cambridge University Press.

Saha, S. K. (2016). Cyclone Aila, livelihood stress, and migration: empirical evidence from coastal Bangladesh. *Disasters*. https://doi.org/10.1111/disa.12214.

Sander-Regier, R., et al. (2010). Planning for climate change in Canadian rural and resource-based communities. *Environments, 37*(1), 35–57.

Schade, J., Faist, T., & McLeman, R. (2015). Conclusion: inequality and migration as adaptation: where do we go from here? In R. McLeman, J. Schade, & T. Faist (Eds.), *Environmental migration and social inequality* (pp. 203–228). Dordrecht: Springer.

Schelling, T. C. (1978). *Micromotives and macrobehavior*. New York: W.W. Norton & Company.

Semenza, J. C., et al. (2008). Public perception of climate change: voluntary mitigation and barriers to behavior change. *Am J Prev Med, 35*(5), 479–487.

Shen, S., & Gemenne, F. (2011). Contrasted views on environmental change and migration: the case of Tuvaluan migration to New Zealand. *Int Migr, 49*(S1), e224–e242.

Smit, B., & Skinner, M. (2002). Adaptation options in agriculture to climate change: a typology. *Mitig Adapt Strateg Glob Chang, 7*(1), 85–114.

Smit, B., & Wandel, J. (2006). Adaptation, adaptive capacity and vulnerability. *Glob Environ Chang, 16*(3), 282–292.

Smith, C. D. (2014). Modelling migration futures: development and testing of the rainfalls agent-based migration model—Tanzania. *Climate and Development, 6*(1), 77–91.

Speare, A. (1974). Residential satisfaction as an intervening variable in residential mobility. *Demography, 11*(2), 173–188.

Stark, O., & Bloom, D. E. (1985). The new economics of labor migration. *The american economic review, 75*(2), 173–178.

Tacoli, C. (2009). Crisis or adaptation? Migration and climate change in a context of high mobility. *Environ Urban, 21*(2), 513–525.

van Aalst, M., Cannon, T., & Burton, I. (2008). Community level adaptation to climate change: the potential role of participatory community risk assessment. *Glob Environ Chang, 18*(1), 165–179.

Warner, K., & Afifi, T. (2014). Where the rain falls: evidence from 8 countries on how vulnerable households use migration to manage the risk of rainfall variability and food insecurity. *Climate and Development, 6*(1), 1–17.

Weber, E. U. (2010). What shapes perceptions of climate change? *Wiley Interdiscip Rev Clim Chang, 1*(3), 332–342.

Wolpert, J. (1966). Migration as an adjustment to environmental stress. *J Soc Issues, 22*(4), 92–102.