Climate Risk Management 33 (2021) 100337

Contents lists available at ScienceDirect

Climate Risk Management

journal homepage: www.elsevier.com/locate/crm

Climate-induced managed retreat in the U.S.: A review of current research

Leah A. Dundon [a,*], Mark Abkowitz [b]

[a] Vanderbilt University, Department of Civil & Environmental Engineering, 2301 Vanderbilt Place, PMB 351831, Nashville, TN, 37235, United States

[b] Vanderbilt University, Department of Civil & Environmental Engineering, PMB 351831, 2301 Vanderbilt Place, Nashville, TN 37235, United States

ARTICLE INFO

Keywords:
Managed retreat
Climate risk
Transformative adaptation
Infrastructure risk
Transportation climate risk

ABSTRACT

Human responses to climate change are continuing to evolve. At one time, mitigation (reduction) of human emissions of greenhouse gases appeared to offer the best response to prevent the worst impacts of a changing climate. It soon became clear, however, that the world would not be able to reduce emissions quickly enough or to a level sufficient to prevent, in the words of the United Nations Framework Convention on Climate Change, "dangerous anthropogenic interference with the climate system". Climate change is already altering the frequency and severity of extreme weather events worldwide, and these trends are expected to increase in the foreseeable future. Accordingly, it is well recognized that adapting in place to the changing climate is necessary. Yet, that may not be enough. An additional step in responding to climate risks is emerging, one that requires fundamentally and permanently changing the human interactions with nature in parts of the world. This strategy is often referred to as "managed retreat," but that term has become controversial, and other terms are needed that express inclusion of the positive societal benefits that can emerge from proactive action. This paper provides a review of the emerging themes within the literature of managed retreat as a climate risk management approach, uses examples from the transportation and infrastructure sector, collects and identifies important nomenclature and definitions, key decision-making considerations, and research gaps that warrant immediate attention. The results of this review are intended to be useful to academic climate change adaptation researchers and infrastructure practitioners alike.

1. Introduction

Climate-induced managed retreat—the basic concept of permanently moving people or infrastructure out of harm's way—is a nascent field with a small, but growing, body of research, led by work conducted in Europe in terms of the number and breadth of peer-reviewed academic studies and professional literature as indicated by searches on Google Scholar (Blott and Pye, 2004; Hazelden et al., 2001; Klein and Bateman, 1998; Krolik-Root et al., 2015). Hino et al (2017) documented and evaluated the (then) most recent retreat projects globally and only three of twenty seven projects evaluated were occurring or had occurred in the United States. Work outside of the United States therefore serves as an important resource as managed retreat concepts more firmly take root in the U.S. As climate change impacts continue to increase and international mitigation goals are not yet being achieved, adaptation in place is now well

* Corresponding author.
E-mail addresses: leah.a.dundon@vanderbilt.edu (L.A. Dundon), mark.abkowitz@vanderbilt.edu (M. Abkowitz).

https://doi.org/10.1016/j.crm.2021.100337
Received 21 September 2020; Received in revised form 4 June 2021; Accepted 10 June 2021
Available online 15 June 2021

recognized as an important component of the global response to climate change (IPCC, 2018; UNFCCC, 1992). However, managed retreat is slowly emerging as an additional strategy that will be a necessary part of the human response to climate change. Accordingly, further focus on managed retreat issues will be needed across a range of disciplines. For example, the U.S. Cybersecurity & Infrastructure Security Agency (CISA, n.d.) has identified sixteen critical infrastructure sectors deemed vital to the functioning of the country. One of those is the transportation sector, and transportation infrastructure is often the subject of managed retreat conversations, such as when re-flooding of roads or bridges demands examination of the wisdom of repeated repair and restoration. Indeed, research on transportation-related managed retreat concepts or practices, where it exists, tends to focus nearly exclusively on roads, with less research devoted to other modes. Although the examples used by the authors herein draw from the transportation and infrastructure sector, this review is applicable to a broad range of sectors because the emerging managed retreat research can, and should be, informed from an interdisciplinary perspective. Moreover, as discussed below, the term managed retreat itself is controversial and can be an impediment to successful retreat policies (Rott, 2018). The authors prefer the term transformative adaptation, but use the term "retreat" in this paper because it is the term used most often in the literature being examined herein.

In the U.S., managed retreat has occurred largely through post-disaster federal- or state-funded home buyout programs, with little pre-event planning (Siders, 2019a). Approaching managed retreat in this way, however, is not likely to adequately address the magnitude of the changes that climate change will bring. Current approaches also are not consistent and often lack a comprehensive plan that would maximize benefits to both the displaced and receiving communities (communities or areas where formerly displaced people move to settle permanently). Rather, managed retreat in the U.S. tends to be ad hoc, isolated to a few homes or small sections of infrastructure, and accomplished in a piecemeal way only after (an expensive) disaster strikes.

The study of managed retreat in the U.S. is also highly focused on coastal areas, primarily because of obvious flooding risks associated with sea level rise and storm surge in those locations. However, population pressures and changing extreme weather patterns (such as increased precipitation that expands river flood plains or increasing drought that limits water availability or river navigation) make some inland areas highly vulnerable. Accordingly, there is a significant need for literature to also address managed retreat in non-coastal areas.

In addition to removing or relocating expensive infrastructure (e.g., buildings, roads, ports), there are significant psychological and practical challenges preventing managed retreat from becoming a viable option (Siders, 2019a; Agyeman, et al., 2009). For example, the U.S. flood insurance program has operated at a deficit for years, depending entirely on continued bailouts from Congress. Many argue the program encourages building in flood prone, increasingly risky areas because the true risks and costs are not known to or experienced by the homeowners, developers, or even local community officials. In December 2019, Congress extended the program's authorization only through September 30, 2020, at which time Congress and the Federal Emergency Management Agency (FEMA) will need to decide whether to cease selling or renewing flood insurance policies for millions of properties (National Flood Insurance Program, 2019).

Using retreat or relocation as the country does now – as a post-hoc response to a disaster in one locality – may prevent achievement of substantial economic, social, and perhaps ecological benefits that could be realized with the adoption of a comprehensive, planned strategy. As Siders suggested in arguing for a comprehensive plan that includes large scale retreat, an appropriate national discussion "might require Americans to reconceptualize our relationship with risk and what it means to own property" (Siders, 2019a).

This paper provides a review of the emerging themes within the literature of managed retreat, as well as important nomenclature and corresponding definitions, key decision-making considerations, and research gaps that warrant immediate attention. It represents the first in a series of articles focused on managed retreat being prepared by the authors which, taken collectively, argues for a comprehensive approach to managed retreat in the U.S., examines specific case studies, and sets forth a framework for managed retreat decision-making. A concurrent goal of this paper is to assist academics focus on the needed research in the managed retreat literature, which ultimately will serve to improve legal and policy responses by public planners who are already being called on to address issues of retreat and relocation of people and infrastructure. Accordingly, the paper ends with a review of existing frameworks and tools, and suggestions for both academic and applied researchers to expand on tool development, especially so that communities can even begin to have these needed conversations.

2. Understanding managed retreat: terms and meaning

2.1. Terminology

A variety of terms are being used to describe the decision-making processes and actions taken in response to climate change that we commonly characterize as "managed retreat." These respective terms typically refer to activities that include moving or relocating people or assets from a vulnerable location, or deciding not to build in or move to areas that previously would have been considered for development or habitation.

The most popular term to describe this phenomena is "managed retreat;" however, use of this phrase can have problematic and controversial connotations, indicating failure and financial loss (Koslov, 2016; Campbell and Wilson, 2016; Carey, 2020). Koslov (2016) provides context for this negative association and the etymological history of the word "retreat". Accordingly, a number of other terms have evolved in the literature. Esteves (2014a, 2014b) and Bilkovic and Mitchell (2017) describe many of these terms, including "strategic retreat", "strategic or managed relocation", "planned relocation", "transformative adaptation," "managed realignment", "resilient relocation," or "habitat restoration."

We prefer use of the term "transformative adaptation" for several reasons. First, the term "managed retreat" has engendered such negative connotations that it may be politically infeasible to undertake any projects in some regions if the term "managed retreat" is

associated with it. Second, "transformative adaptation" includes the potential positive co-benefits—social, economic, and ecological—that can be realized through such fundamental changes undertaken in response to climate change. Finally, fundamental changes such as moving people and infrastructure permanently away from a particular area and allowing nature to reclaim that area, are a means of *adapting* to a changing climate. Indeed, Braamskamp and Penning-Rowsell (2018) and Freudenberg et al. (2016) discuss managed retreat as an adaptation option. Such a measure may be considered different in character or type than activities we often more typically consider as "adaptation"—e.g., installing a sea wall or changing crops in response to a new growing season—but these activities are inherently actions we take to adjust, or adapt, to the new climate within which humans now are finding ourselves. Notably, the UNFCCC, 1992, defines climate change "adaptation" as an "[a]djustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities" (IPCC, 2020), this could certainly include activities associated with managed retreat strategies. Of particular note is that the UNFCCC glossary does not include "retreat" or other synonyms commonly used to identify managed retreat policies. Despite the authors' preferred term of "transformative adaptation," we continue to use the term "managed retreat" in this paper because the vast majority of the literature described herein uses this term.

2.2. Meaning

As in the case of managed retreat terminology, definitions also vary by author, location, and over time (Koslov, 2016; Neal et al., 2005). As shown in Table 1, definitions of retreat-related terms range from a narrow focus on coastal retreat due to sea level rise and storm surge (Esteves, 2014a; 2014b), to a strategy of retreat from any area in order to manage natural hazard risks (Hino et al., 2017), to a general meaning that encompasses a "suite of adaptation options" (Siders, 2019b).

As previously noted, we prefer use of the term "transformative adaptation," but recognize that other terms are acceptable and language used should take account of local preferences and values. However, it is important to note that terms such as "relocation" have considerable racist overtones, from the forced relocation of Native Americans to the internment of Japanese Americans during World War II. Accordingly, thought should be directed to effective outcomes, rather than adopting existing language that could be divisive. There will be regional differences in what terminology is likely to be effective; an approach is more likely to be successful if the terms and meanings are adopted early, and if the definitions used take into account the goals of the particular project and the culture of the area.

In this paper, we build on the existing definitions noted in Table 1 and define transformative adaptation as: permanent or long term change in where and how humans live that is a direct response to a permanently changing climate. This definition is deliberately intended to expand the definition of these types of permanent changes beyond mere retreat. Using the term 'managed retreat' to encompass *only* the movement or relocation of people or infrastructure is too limited and that limitation has proved problematic (Koslov, 2016; Campbell and Wilson, 2016; Carey, 2020). Accordingly, the term "transformative adaptation" would include moving/relocating people or infrastructure, but it is broad enough to include other measures that serve similar, permanent goals but that may not carry negative associations.

3. Classifications

Existing managed retreat studies can be organized into the following topical areas: 1) coastal retreat, 2) law, policy and planning, 3) climate and social justice, 4) infrastructure and 5) frameworks and tools. Although there is significant overlap in these concepts, and many researchers argue for a more holistic view of managed retreat programs, these classifications can be useful to practitioners. The ensuing discussion examines these categories, identifies gaps in research and knowledge, and suggests additional areas of focus needed in the study and practice of managed retreat.[1]

3.1. Coastal retreat

Perhaps not surprisingly, managed retreat in the context of coastal flooding from sea level rise and storm surge dominates the literature. Utilizing a Google Scholar search, over the last two decades, only 105 articles contained the term "managed retreat" in their titles. Most of these came from outside the U.S., and approximately 90% of these studies addressed primarily or exclusively retreat involving coastal issues (e.g., Townend and Pethick, 2002; Dachary-Bernard et al., 2019a,b; Olufson, 2019).

Siders (2019a); (2013;) argues for a comprehensive national plan for coastal retreat and adaptation that could include such approaches as dramatically expanding the National Seashore. National Seashores are akin to National Parks, they are coastal areas that are owned and managed by the federal government, set aside typically for public, recreational use (Repanshek, 2007). Accordingly, their expansion could prevent building in vulnerable coastal areas, or remove existing infrastructure. Braamskamp and Penning-Rowsell (2018) and Healy and Soomere (2008), taking a more pessimistic view, have noted that effective coastal managed retreat programs are not likely to occur proactively, and that successful examples typically occur only in response to a disaster. However, there are case studies of efforts underway in the U.S. and elsewhere to implement managed retreat as a response to beach loss (Abbott, 2014; Daniel, 2001; Dyckman, et al., 2014; Van Alstyne, 2015; Esteves, 2014a; 2014b;; Esteves and Williams, 2017; Rulleau and Rey-Valette,

[1] Because the literature primarily uses the term "managed retreat," the authors will continue to do so in this literature review.

Table 1
Managed retreat terms and definitions.

Source	Term used	Definition
Ajibade, et al., 2020	Managed retreat	"the deliberate and strategic 'move from climate-induced harm' – this encompasses moving people and the resources they value such as homes, businesses, infrastructure, ecosystems, and other assets from areas of risk and resettling them in safer locations"
Koslov, 2016p. 362	managed retreat	"the relocation of people to higher ground and associated efforts to plan and manage that movement. In practice, however, this often means restricting movement as much as facilitating it."
Siders et al., 2019	strategic and managed retreat	"a suite of adaptation options that are both strategic and managed. Strategy integrates retreat into long-term development goals and identifies why retreat should occur and, in doing so, influences where and when. Management addresses how retreat is executed."
Siders, 2019a	managed retreat	the purposeful, coordinated movement of people and assets out of harm's way
Doberstein, et al., 2020, p.1	managed retreat	"reduce the exposure of people and assets to flooding, storm surges and sea level rise by retreating from these threats in a planned fashion."
Braamskamp and Penning-Rowsell, 2018, p. 108.	managed retreat	"permanent resettlement of existing households and communities away from areas at risk."
Esteves, 2014a; 2014b, p. 19.	managed realignment	"a general term that can be used to describe collectively the many mechanisms implemented to allow coastlines to evolve more flexibly with the objective of promoting more sustainable flood and erosion risk management."
Bronen, 2011, p. 109	community relocation or managed adaptive retreat	A program in which "livelihoods, housing, and public infrastructure are reconstructed in a location, away from vulnerable risk-prone coastal and riverine areas …"
Dannenberg et al., 2019	planned relocation	"a proactive response prior to catastrophic necessity."
Hanna, et al., 2019	managed retreat	"a deliberate strategy to remedy unsustainable land use patterns that expose people, ecosystems, and assets to significant natural (and socio-natural) hazard and climate induced risks" or "the strategically planned withdrawal from development in risky spaces."
Hino, et al., 2017, p. 364	managed retreat or transformational adaptation	"the strategic relocation of structures or abandonment of land to manage natural hazard risk."
Cooper, 2003	managed retreat	"the deliberate breaching, removal or landward relocation of an existing tidal defence or coastal protection structure."
Townend and Pethick, 2002, p. 1477	managed retreat	In the U.K., an effort to "restore previously reclaimed areas in order to reduce flooding and other hazards of the estuarine system."
Alexander et al., 2012, p. 409.	managed retreat	"the relocation of homes and infrastructure under threat from coastal flooding"
Agyeman, et al., 2009, p. 509.	managed retreat	"the relocation of communities and ecosystems."
Lawrence, et al., 2020	managed retreat	"planned retreat that removes people and their assets away from hazards such as sea-level rise and flooding—pre-emptively and permanently."
Koraim, et al., 2011, p. 47.	managed retreat	"a strategy that safely removes settlement from threatened shorelines, allowing the water to advance unimpeded. It involves abandoning, demolishing or moving existing buildings and infrastructure to higher ground. It also includes banning new development in areas likely to be inundated." In addition, the "managed" aspect "involves establishing thresholds to trigger activities such as demolishing buildings or abandoning efforts to control shoreline erosion. These thresholds can be coupled with buy-back programs to compensate property owners for loss, plus strict building codes that allow only certain types of re-locatable or floodable structures.
Plastrik & Cleveland, 2019, p. 3.	managed retreat	An approach that "uses public policies, including regulations, investments, and incentives to remove existing development—buildings, infrastructure, entire neighborhoods—over time and prevent future development in parts of the city that cannot, should not, or will not be armored or accommodated for potentially devastating climate hazards."
Hamilton, et al, 2016, p. 1.	climigration	Migration caused by climate change."This term is often used to describe the permanent relocation, or movement, of a group of people away from their home to another area caused directly by climate-induced events. This could be large scale climate-induced drought making continued farming in an area impossible or difficult, or sea level rise that makes continued coastal habitation impossible or difficult.

2017). Dannenberg et al. (2019) has studied the health impacts of retreat in coastal communities and determined that additional work is needed to understand how to increase a community's resilience to retreat. There is also evidence that, properly implemented, managed retreat in coastal wetland areas may have carbon sequestration co-benefits (Rogers et al., 2014). Co-benefits of retreat programs are often overlooked and understudied in the literature.

The emphasis on coastal retreat overlooks the importance of studying retreat in non-coastal areas. For example, inland river flooding in the U.S. has had substantial economic and human livelihood consequences, and is on an upward trend in part due to climate change (Zhou et al., 2019). The City of Nashville (not unlike other U.S. cities) has a major navigable river that transects its metropolitan downtown business district. In 2010 the city experienced a 1 in 1000 year flood event due to excessive rain that caused the river to swell to record levelseur, causing more than $2 billion in damages, destroying thousands of businesses, and killing 11 people. Managed retreat literature's focuses on coastal areas overlooks thinking about whether, and how, to maintain expensive city infrastructure directly on riverbanks—even if the benefits of remaining in place ultimately are determined to outweigh the costs to retreat, it is a needed conversation so those stakeholders that bear the financial and physical risks are alerted. National Flood Services, a company that services private and government flood insurance products, such as insurance issued by the National Flood Insurance Program, has expressly recognized that inland flooding is increasing and is often overlooked (NFS, n.d.) by the focus on coastal

flooding. Moreover, extreme heat, precipitation and drought are increasing in frequency and severity in some inland areas of the U.S., and may have a major impact on the ability to maintain farming or to continue farming climate-sensitive crops. There may be similarities in response options between the extreme events in the context of urban heat or inland flooding and the traditional notions of retreat that we associate with coastal flooding. Broadening the narrative also may allow retreat options to be more actively considered in non-coastal settings, and may also serve to expand ideas for retreat—or transformative adaptation options—in the coastal context (Loeb, 2017).

3.2. Law, policy, and planning

Perhaps the most challenging subject in the study of managed retreat is how to design and implement effective policies and programs that have public support, will protect human life and livelihoods, and will preserve the public financial resources that are often the "last stop" for some citizens when a disaster occurs (Hanna et al., 2019). Determining what existing laws provide opportunities to be leveraged, and what new laws or policies are needed to move forward effectively are important considerations the research community is only beginning to address. The example of local government duties and obligations to maintain transportation infrastructure (noted below) is an important illustration of this problem. Substantially more work is needed to guide local, state, and federal policy makers who face the expectation that public and private services (e.g., roads, mail, utility delivery, access to work and entertainment venues, supplies and food, etc.,) will continue to operate as always despite a changed climatic environment.

A number of authors have collectively advanced the research in this area in recent years. Mach et al. (2019) completed detailed analyses of all FEMA-funded home buyouts across the United States, and Nguyen (2020), Mach et al. (2019) and others have recognized that home buyout programs tend to be the primary (and in most areas, only) program through which managed retreat is implemented (Byrne & Grannis, 2012; Mach et al., 2019). However, buyout programs are often accomplished without serious planning that relates more comprehensively to a community's goals, and may be utilized only after a disaster has occurred. *Id.*

As home buyout programs are typically subject to a patchwork of federal, local, and state laws, while they may be effective in a particular location and bring a myriad of benefits (reducing infrastructure and people in hazard areas, increasing green space and flood protection), they do little to contribute to a national strategy. Areas of Canada, however, have implemented buyout policies that encourage or require retreat. For example, Gatineau, Canada, requires abandonment of some homes if more than 50% of the value of the home is destroyed. For other homes, the program will compensate only $100,000 USD for damage repair, but will pay up to $250,000 for a buyout of the home no matter the actual market value. However, if the owner elects to take the compensation for repairs, the government will not provide any future support if the home is flooded again (Carey, 2020). However, there is less emphasis in Canada on individual property rights and more emphasis on the public good than in America, raising important cultural issues that may make retreat more difficult in the U.S. In addition, the legal frameworks in the two countries differ in important ways that both contribute to these cultural differences and make implementation of managed retreat in the U.S. potentially more difficult. For example, the Takings Clause of the Fifth Amendment to the U.S. Constitution, and counterparts in state constitutions, require a legal process (often lengthy and expensive) before the government can "take" private property (for managed retreat programs or otherwise). The law also requires that the taking be for a public purpose and the government must pay "just compensation" to the property owner (Ruppert, 2018). By contrast, in Canada, (based on the law of England), all land is owned by the Crown, so the expectation (and right) to private property is very different (Jeffery & Vaughati, 1993). Accordingly, successful implementation of retreat policies is also jurisdiction dependent (Hanna et al., 2021).

Study of impacts to receiving communities is also sorely needed (Hanna et al., 2019). The focus to date has predominately been on policies and practices to remove people or infrastructure from high risk areas, without consideration of advance planning regarding where those people will go, and the types of impact receiving communities will experience, such as effects on their infrastructure, social cohesion, and economic well-being. Both positive and negative impacts to receiving communities should be well understood as part of a comprehensive plan in order to increase positive outcomes and reduce negative impacts on both the receiving and relocated communities. The relocation of the inhabitants of the Isle de Jean Charles in Louisiana—the first federally funded project of its kind in the U.S.—is an early example of a concerted effort to entirely relocate a population that could no longer be sustained on its disappearing island (Louisiana Office of Community Development, 2020).

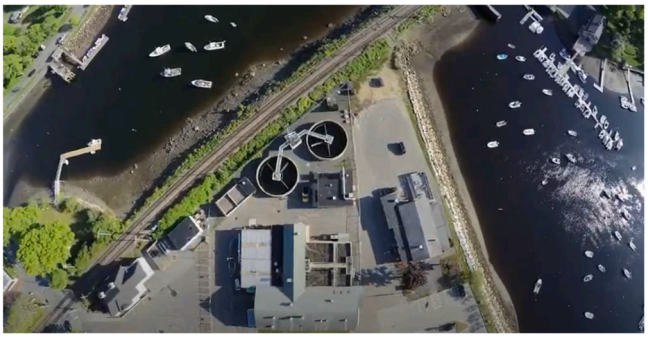

Fig. 1. Manchester by the Sea, MA; water treatment plant located directly on the ocean just 10 feet above sea level.

Environmental laws in particular should be examined to determine where there may be a relationship to managed retreat concepts. For example, although we typically think of private corporations as holding permits to discharge pollutants, public entities such as waste water treatment plants are subject to the same or similar permitting requirements before they can discharge pollutants to rivers and streams. Water quality criteria of the receiving water bodies is directly related to the permit conditions of the discharger. Changes in precipitation patterns (floods or droughts), aging water treatment infrastructure, and temperature increases in the receiving waterbody can all impact the financial bottom line of a treatment plant, which is funded entirely by the taxpayer. Indeed, EPA has provided funding in recent years to substantially upgrade wastewater treatment plants that are vulnerable to sea level rise (EPA, 2017).

Although the waste water treatment plant at Manchester by the Sea (Fig. 1) and many others in climate vulnerable locations across the country are nearing or have exceeded their design life, serious conversations are not being held about whether, how or where to rebuild them. The negative health impacts of combining old infrastructure with climate change events has also been well documented in the literature (Jagai et al., 2015). The authors (Jagai et al., 2015) studied the relationship between extreme precipitation events and old combined sewer systems (systems still in current use in the majority of the United States where storm water and sewage flow is combined and designed to overflow into creeks and rivers during high rain events) and found in some areas a significant increase in risk for gastrointestinal illness during extreme rain events. We are aware of no clear framework for incorporating these types of costs and burdens (e.g., health impacts, indirect tax burdens) to a community when weighing the costs and benefits of retreat versus remaining or fortifying.

Early identification of clear societal goals, and the integration of retreat polices and practice with these goals, effectively communicated between public and policy makers, are essential elements of success for managed retreat programs, especially in the U. S. (Siders et al., 2020; Greiving et al., 2018). Such a strategy is still lacking, perhaps because it has only recently become clear that traditional notions of adaptation are not likely to be sufficient in some areas, and managed retreat must be considered. Lawrence et al. (2020) discusses some of the governance and planning gaps in managed retreat implementation and suggests reforms that include minimizing long term costs, making public risk assessments available, offering better coordination between different levels of government, increasing incentives, and avoiding the characterization of retreat as the "last" option. Building on Lawrence et al.'s (2020) recommendation for better coordination between levels of government, Hanna et al. (2021) have developed a retreat governance framework that employs a "governance continuum," which can be useful to determine what level of government (if any) and what tools might be available to implement retreat practices. Hanna et al. (2021) also draws from the extensive literature on human mobility.

Plastrik & Cleveland (2019) define three kinds of retreat: 1) traumatic post-disaster retreat, 2) chaotic, market-driven retreat, and 3) forward-looking planned retreat. Siders (2013) has identified five legal mechanisms by which society can move towards planned retreat: 1) increased coastal management, 2) greater regulatory use of setbacks and easements, 3) regulations that prevent continued armoring of coastal areas, 4) restrictions on rebuilding after a disaster, and 5) buyout programs. However, law and policy should be used to not only prevent activities that increase risk or make communities more vulnerable, but should seek to incentivize activities that reduce risk or vulnerability.

Knowledge gaps include a better understanding of effective public communication strategies to increase local "buy-in." For example, the psychological theory known as "place attachment" is only beginning to be explored in the context of managed retreat, but has been recognized as a substantial barrier to successful managed retreat programs (Agyeman et al., 2009). This theory recognizes that people form deep and profound bonds with physical locations (Gurney et al., 2017). Plastrik and Cleveland (2019) have posited that place attachment runs so deep that the psychological phenome of the "five-stages of grief", identified in the 1950s describing how people react to personal loss, is entirely applicable to being asked to leave one's home or community because of climate change. More effective communication and messaging strategies in high risk areas where place attachment runs deep are critical to successful outcomes (Hanna et al., 2020).

There is also a lack of studies focusing on financial considerations. People being asked to support a local (or national) retreat program often lack access to the information needed to understand the true financial cost of failing to retreat. This may be because the true costs are complex and often hidden, involving a web of federal, state, or local disaster funding, private or subsidized insurance, and short-term incentives and tax-breaks (that are funded by the public) that may have drawn expensive infrastructure to risky locations in the first place. Untangling this web to understand and effectively communicate the true financial costs can be difficult.

Plastrik & Cleveland (2019) found that buyouts are the only retreat program through which cities can at least hope for some financial support from state or federal government, and often only after a disaster. Many buyout programs are, however, available pre-disaster, but are voluntary programs and are often not taken advantage of until after a disaster. This was the case in the City of Nashville, which has had a voluntary buyout program for many years, but it saw dramatic increase in utilization after the 2010 flood, with 305 homes purchased in just the first phase after the flood (Metropolitan Government of Nashville, 2011). Buyout programs also typically fail to consider the collective good and comprehensive retreat strategies, and instead focus on individual homes. Financial support that can be tapped pre-disaster and that will support a long-term perspective is critical, but currently unavailable. Other approaches to retreat, such as changes to zoning or setbacks, still implicate needed resources although less directly than the need for cash payments for homes. For example, changes to zoning that limits development in an area reduces the tax base and therefore revenue for the city if that revenue is not made up elsewhere. In general, managed retreat approaches are under resourced.

3.3. Climate and social justice

It is well documented that the most vulnerable members of society are the most vulnerable to climate change impacts (Siders, 2019b). They tend to live in areas with greater exposure to extreme weather events, lack the protective infrastructure to avoid harm,

and when disaster occurs, lack the resources and networks that enable more affluent people to recover more quickly. If people are unable to continue living in their home and have the means to do so, they relocate to a different location. This is true at every scale, from the individual to the national level. When entire communities or nations seek permanent relocation in response to climate change, this is often referred to as "climigration." Frameworks are emerging that recognize climate-induced migration as an inevitable part of the changing global socio-political landscape, and that human rights principles must be part of any interventions or solutions (Bronen, 2011; Rush, 2019; Ajibade, 2019).

Within the U.S., managed retreat has been accomplished primarily through home buyout programs, but these programs can exacerbate existing social inequalities. Siders (2019b) argues that increased transparency and awareness of bias and social inequalities in buyout programs is needed. Governments also may be more willing to implement buyout programs in areas with specific demographics, contributing to inequalities (Mach, et al., 2019). The social justice implications of buyout programs are critical to fully understand, because they continue to be the most available—and currently most important tool—to effect managed retreat policies (Freudenberg et al., 2016; Maldonado et al., 2014; Insurance Journal, 2020).

3.4. Infrastructure

The entrenchment of expensive and long-lived infrastructure in areas that are increasingly exposed to extreme weather events is one of the most challenging aspect of developing successful managed retreat plans. Infrastructure such as roads, office or residential buildings, sewer systems and water treatment plants typically have design lives of several or many decades, and it can seem impossible to "move" these major structures out of harm's way. In coastal cities, beach replenishment and home buyouts have been the primary options pursued, but Nash, et al. (2005) suggest another alterative, which is to develop phased plans in 10-year increments over a 100-year time frame, as needed. This novel approach provides the first 10 years to plan, and requires consideration of the costs of continuing to armor or defend existing infrastructure over a defined time horizon as compared to the cost of demolishing and rebuilding elsewhere. *Id.* As Nash has recognized, "virtually all coastal communities will need such programs of managed retreat over the next 100 years, or they will fulfill the prediction of retreating as the result of a series of coastline calamities" (Nash, et al., 2005, p. 605). There are also substantial political difficulties with retreat policies, as documented by Scott et al. (2020). Infrastructure vulnerability is not only caused by climate change, but by conscious choices to continue to build in (increasingly) risky areas, such as in fire-prone areas and coastal areas (Scott, et al., 2020; Larsen et al., 2008).

Research has begun to focus in earnest on the impacts of climate change to transportation infrastructure and the need for retreat (Ruppert et al., 2019). However, like coastal areas, roads dominate any discussion of how managed retreat programs may apply to transportation infrastructure (e.g., Fialkoff, 2017; Deady, et al., 2017; Jones et al., 2019; Ruppert and Grimm, November 2013). Ruppert et al. (2019) examined an important factor that may inhibit managed retreat programs from even being conceived in the transportation context; that is, the limits of local government authority and their corresponding duties under the law. In some areas, local governments may have a legal obligation to continue to maintain a road once it is there. These localities may face lawsuits from residents unable to access their property if a road is abandoned, as effecting an unconstitutional "taking" of their property without just compensation. The changing climate in areas where public roads or other infrastructure is at increased risk of damage has exacerbated tensions between the welfare of the larger community and the individual property right protections in the U.S. Constitution. Ruppert, *et al.*'s work highlights the need for state and federal government coordination and for state intervention in some cases, because local governments only have the authority granted to them by the State (Dundon and Abkowitz, 2018).

Managed retreat in the inland waterway context is nearly entirely missing from work being undertaken in the United States; however, European researchers provide an important resource in this area. Freight shipping by barge is one of the lowest cost and most environmental friendly shipping modes that exists (U.S. DOT, 1994). Yet, it is clear that inland waterway navigation is vulnerable to climate change (especially from increased droughts and floods that make navigation dangerous or impossible), and effective adaptation or retreat strategies may be overlooked.

The economic consequences of disruptions to the inland waterway systems have been studied. (Olsen, et al., 2005; Koetse & Rietveld, 2009; Jonkeren, et al., 2014; Fealy & Murphy, 2009a; 2009b). Managed retreat in the inland waterway context, however, is a nascent field with extremely limited work, with only one study in the U.S. that expressly addresses U.S. inland waterway transportation and managed retreat (Osman, 2017). That study discussed the major successes Illinois has had in expanding the floodplain, relocating communities and removing flood-prone infrastructure, but also noted that "accurate climate change data on major inland waterways and urban areas remains elusive." Zheng & Kim's work (2017) highlights the need to think of managed retreat more broadly in the inland waterway context. Using a river in Northern Canada as an example, the authors highlight that shipping schedules may need to permanently change, a type of "retreat" from business as usual under a previously stable climate.

Coastal ports in the U.S. are more likely than inland waterways to be considered regarding climate change risks. For example, the U. S. port of Norfolk, Virginia is experiencing major impacts from both sea level rise and land subsidence, making it one of the most vulnerable ports in the U.S., and it is also a major military installation. The city does not use the term retreat, but is working on policies that will have citizens "gradually decide to leave as the inconvenience of staying grows" (Morrison, 2020). However, Norfolk, like many cities, also continues to invest in resiliency efforts, which researchers have cautioned may create a "negative spiral" of encouraging more investment in infrastructure and obfuscating the real risks (*Id.*). More research is urgently needed to determine if the unintended consequences of resiliency efforts are likely to do more harm than good in the long term, because "resiliency" efforts have become the primary focus of many communities as a method to address climate change risks.

Substantial work is needed to examine how and whether climate data can be better utilized in the inland waterway context, and to determine what inland waterway transportation stakeholders are facing regarding shipping under changing climate conditions and

how they view potential responses. A framework for decision making that takes account of these variables will be important to future developments in this field.

Equally lacking in the field of managed retreat research is work on railway infrastructure. Roads and rail lines are both extremely expensive to rebuild or to relocate often requiring new land purchases or eminent domain proceedings to take new land (if relocation is the selected approach). One example presented by Rutledge (2018) involves the Burlington Northern Santa Fe Railway line at the western U.S. and Canada border. Two nearby cities in British Columbia are evaluating retreat options for a portion of the rail line that has become increasingly vulnerable to weather induced events, at a cost of $350-$450 USD million. For any managed retreat discussion to succeed with these types of costs, multiple stakeholders at all levels of government and private industry must be engaged (Rutledge, 2018). While rail lines traverse our nation, many are located directly on vulnerable coastal properties, cliffs or near riverbanks that will be increasingly vulnerable to extreme weather impacts (Fig. 2).

Airports and pipeline infrastructure are also just beginning to enter the managed retreat conversation. For example, Hawaii has long recognized the need to address climate change impacts, and recently issued a report on managed retreat in its coastal areas that addresses transportation infrastructure (State of Hawaii, 2019). The report notes that much of Hawaii's critical transportation infrastructure, including airports, is located on or near vulnerable coasts.

U.S. airports are at risk of permanent water inundation by the end of the century. Airports located in New Orleans, La Guardia (New York City), and Key West (Florida) all face critical threats from sea level rise and storm surge. Some U.S. airports have already installed flood barriers, such as Boston and San Francisco (Lavietes, 2020). Outside the U.S., small island nations often lack funding to undertake these types of infrastructure changes, and major development banks are often left to determine whether to continue repairing a literally drowning asset (World Bank, 2017). In the international development context, these decisions are often inextricably linked to issues of place attachment and social justice (poor island nations have not contributed meaningfully to the causes of climate change), but climate migration is likely to be inevitable.

In the northern hemisphere, a substantial amount of pipeline infrastructure is built on permafrost. If climate change causes that permafrost to melt, as expected, these pipelines are at risk, in addition to the major ecological damage from the attendant chemical spills if a pipeline fracture occurs (Hjort et al., 2018).

Although this section addresses primarily transportation infrastructure, other major infrastructure is largely missing from academic studies focused on the need for managed retreat. For example, water infrastructure such as wastewater treatment systems, are aging and nearly always located in low-lying areas on coasts or rivers. Most communities in the U.S. also use aging combined sewer systems, where stormwater and sewer waste are mixed and designed to overflow to rivers and streams. Waste water facilities, sewage systems and storm water systems are facing the dual threats of age and extreme precipitation in many locations. These issues are already being considered by water managers in many cities, but have not yet been adequately addressed by researchers. Kool et al. (2020), however, have modeled a dynamic adaptive pathway planning approach that could be used to identify thresholds for storm water and waste water that would trigger retreat policies that could be implemented over time and budgeted for. Kool et al's approach is an example of a *strategy* for treat that Siders et al.'s (2019) has argued is missing and particularly needed in the infrastructure sector in order to effectuate efficient retreat options that impose co-benefits on society and achieve short and long term societal goals.

3.5. Framework and tools

Practice-ready frameworks and tools are needed to support local, state, and federal decision making around managed retreat. A few are just beginning to emerge. Notably, the Georgetown Climate Center has developed a toolkit designed to help states assess risk and develop legally defensible managed retreat programs rooted in equity (GCC, 2020). As noted above, Kool et al. (2020) have developed a Dynamic Adaptive Pathway Planning (DAPP) approach for managed retreat of major water infrastructure.

Kousky (2014) sees effective retreat programs in the U.S. as unlikely, but proposes a framework for retreat to be implemented post-disaster. Storms, she notes, can be "windows of opportunity for change because they create a forced turnover in capital stock and a

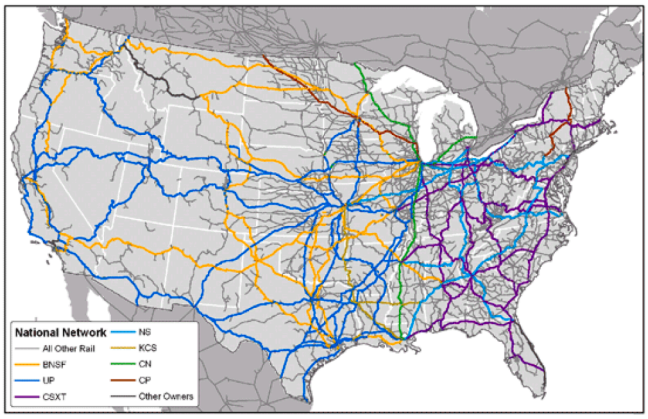

Fig. 2. Major U.S. freight rail lines.

chance to rebuild differently," but she argues that pre-disaster planning for post-disaster reform is critical. At the outset, local governments should carefully and creatively identify revenue sources for retreat programs, such as earmarking sales or hotel taxes, or increasing taxes on new construction in risky areas. Next, use funds to encourage (or require) retreat, utilizing creative mechanisms, such as bonuses for voluntarily moving as a neighborhood to encourage positive social pressure to move together, changing required setbacks, or changing disaster aid to encourage retreat (Kousky, 2014). Finally, limit public building and infrastructure in risky areas, even if private infrastructure remains.

A common thread through this body of work, without being stated explicitly, is that communities should start talking about retreat (through whatever language is appropriate locally) early and often. Retreat should not be seen as a radical, last resort solution to avoid, but as a strategy to consider among others as communities think long-term about their viability and the livelihoods of their citizens in 10, 50, or 100 years (Plastrik & Cleveland, 2019; Linnenluecke et al., 2011; Pinter and Dalbom, 2017).

4. Conclusion

None of the aforementioned considerations exist in silos. Infrastructure is difficult to move in part because it is large and expensive, but also because it is intimately intertwined with human connectedness to place and purpose. Similarly, law directly bears on the feasibility or even authority of any government to undertake regulatory measures implementing retreat options, and the defensibility of those measures when they are challenged. Perhaps even more so than climate change, managed retreat (by any name), to be successful, demands perspectives and information from a broad range of disciplines. Researchers from a diverse group of backgrounds are beginning to come together to discuss these issues, and frameworks are emerging that may be more useful from this multidisciplinary perspective.

Managed retreat (or transformative adaptation) is also not static, and any definition should evolve to include a range of the permanent changes humans make in light of a changing climate (Zheng & Kim, 2017). This could include shifting away from specific crops in certain areas, changes to the types of vessels or scheduling used in inland waterway freight shipping, changes to the flood insurance program to stop rewarding building in high risk areas, or shifts in regulations governing water management practices in areas of increasing drought. Including a broad scope within the term's meaning may make such "transformative adaptation" polices more acceptable and typical, and they may even come to be accepted as the more responsible and reasoned approach to addressing the continued viability of high-risk areas and the well-being of our citizenry.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

The authors would like to acknowledge the Maritime Transportation Research and Education Center at the University of Arkansas, and the assistance of Ms. Rashmi Jha.

Disclaimer

The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the information presented herein. This document is disseminated in the interest of information exchange.

References

Abbott, T., 2014. Managed Retreat in Maui, Hawaii. In: Managed Realignment: A Viable Long-Term Coastal Management Strategy? Springer, Dordrecht, pp. 79–82.

Agyeman, J., Devine-Wright, P., Prange, J., 2009. Close to the edge, down by the river? Joining up managed retreat and place attachment in a climate changed world. Environ. Planning A 41 (3), 509–513.

Ajibade, I., Sullivan, M., Haeffner, M., 2020. Why climate migration is not managed retreat: Six justifications. Global Environ. Change 65, 102187. https://doi.org/10.1016/j.gloenvcha.2020.102187.

Ajibade, I., 2019. Planned retreat in Global South megacities: disentangling policy, practice, and environmental justice. Clim. Change 157 (2), 299–317.

Alexander, K.S., Ryan, A., Measham, T.G., 2012. Managed retreat of coastal communities: understanding responses to projected sea level rise. J. Environ. Plann. Manage. 55 (4), 409–433.

Bilkovic, D., Mitchell, M. (Eds.) (2017). Living Shorelines: The Science and Management of Nature-Based Coastal Protection. CRC Press.

Blott, S.J., Pye, K., 2004. Application of lidar digital terrain modelling to predict intertidal habitat development at a managed retreat site: Abbotts Hall, Essex, UK. Earth Surface Processes and Landforms: The Journal of the British Geomorphological Research Group 29 (7), 893–905.

Braamskamp, A., Penning-Rowsell, E.C., 2018. Managed retreat: a rare and paradoxical success, but yielding a dismal prognosis. Environ. Manage. Sustainable Development 7 (2), 108. https://doi.org/10.5296/emsd.v7i210.5296/emsd.v7i2.12851.

Bronen, R., 2011. Climate-induced community relocations: creating an adaptive governance framework based in human rights doctrine. NYU Rev. L. Soc. Change 35, 357.

Campbell, L. and Wilson, R., 2016. Climate Change Adaptation. Beachapedia.

Carey, J., 2020. Core Concept: Managed retreat increasingly seen as necessary in response to climate change's fury. Proceedings of the National Academy of Sciences. s.

Cooper, N.J. (2003, June). The use of 'managed retreat' in coastal engineering. In Proceedings of the Institution of Civil Engineers-Engineering Sustainability (Vol. 156, No. 2, pp. 101-110). Thomas Telford Ltd.

CISA, (n.d.). Cyber Security & Infrastructure Security Agency. Critical Infrastructure Sectors, available at https://www.cisa.gov/critical-infrastructure-sectors. Accessed May 8, 2021.
Dachary-Bernard, J., Rey-Valette, H., Rulleau, e.B., 2019a. Preferences among coastal and inland residents relating to managed retreat: Influence of risk perception in acceptability of relocation strategies. J. Environ. Manage. 232, 772–780.
Dachary-Bernard, J., Rey-Valette, H., Bénédicte, R., 2019. Refining the analysis of coastal and hinterland community preferences for attributes of managed retreat: the key-role of risk perception.
Daniel, H., 2001. Replenishment versus retreat: the cost of maintaining Delaware's beaches. Ocean Coast. Manag. 44 (1-2), 87–104.
Dannenberg, A.L., Frumkin, H., Hess, J.J., Ebi, K.L., 2019. Managed retreat as a strategy for climate change adaptation in small communities: public health implications. Clim. Change 153 (1-2), 1–14.
Deady, E., et al., Monroe County Pilot Roads Project: The Sands and the Twin Lakes Communities, January 2017.
Doberstein, B., Tadgell, A., Rutledge, A., 2020. Managed retreat for climate change adaptation in coastal megacities: a comparison of policy and practice in Manila and Vancouver. J. Environ. Manage. 253, 109753. https://doi.org/10.1016/j.jenvman.2019.109753.
Dundon, L., Abkowitz, M., 2018. Regulatory and private approaches to addressing impacts to transportation infrastructure from oil and gas operations in rural communities: using the law to build a toolkit for local planners. 45 Transp. L.J. (2018) Issue 2.
Dyckman, C.S., St. John, C., London, J.B., 2014. Realizing managed retreat and innovation in state-level coastal management planning. Ocean Coast. Manag. 102, 212–223.
EPA, 2017. EPA Climate Change Adaptation Resource Center, Manchester-by-the-Sea, Massachusetts Assesses Climate Vulnerability.
Esteves, L., 2014a. Managed Realignment: A viable Long-Term Coastal Management Strategy. Springer.
Esteves, L.S., 2014b. What is Managed Realignment?. In: Managed Realignment: A Viable Long-Term Coastal Management Strategy? Springer, Dordrecht, pp. 19–31.
Esteves, L.S., Williams, J.J., 2017. Managed realignment in Europe: a synthesis of methods, achievements and challenges. In: Bilkovic, D.M., Mitchell, M.M., Toft, J.D., La Peyre, M.K. (Eds.), Living Shorelines: The Science and Management of Nature-based Coastal Protection. CRC Press/Taylor & Francis Group, pp. 157–180.
Fealy, R., Murphy, C., 2009. The likely physical impacts of future climate change on inland waterways and the coastal environment in Ireland. In: Climate Change, Heritage and Tourism: Implications for Ireland's Coast and Inland Waterways. The Heritage Council of Ireland Series. Heritage Council, Kilkenny, Ireland, pp. 39-54. ISBN 9781906304065.
Fealy, R., Murphy, C., 2009. The likely physical impacts of future climate change on inland waterways and the coastal environment in Ireland.
Fialkoff, L., 2017. Louisiana: Transportation Infrastructure Improvement for Economic Development.
Freudenberg, R., Calvin, E., Tolkoff, L., Brawley, D., 2016. Buy-in for buyouts: The case for managed retreat from flood zones. Lincoln Institute of Land Policy, Cambridge, MA.
Georgetown Climate Center (GCC), 2020. Developing a Managed Retreat Toolkit, June 17, 2020, available July 5, 2020 at https://www.georgetownclimate.org/articles/building-resources-for-managed-retreat.html.
Greiving, S., Du, J., Puntub, W., 2018. Managed retreat—a strategy for the mitigation of disaster risks with international and comparative perspectives. J. Extreme Events 05 (02n03), 1850011. https://doi.org/10.1142/S2345737618500112.
Gurney, G., Blythe, J., Adams, H., Adger, W., Curnock, W., Faulkner, L., James, T., Marshall, N., 2017. Redefining community based on place attachment in a connected world. PNAS first published September 5, 2017 https://doi.org/10.1073/pnas.1712125114, Ed. by Anthony J. Bebbington, Clark University, Worcester, MA, and approved August 10, 2017.
Hamilton, L.C., Saito, K., Loring, P.A., Lammers, R.B., Huntington, H.P., 2016. Climigration? Population and climate change in Arctic Alaska. Popul. Environ. 38 (2), 115–133.
Hanna, C., White, I., Glavovic, B., 2019. Managed retreat in practice: Mechanisms and challenges for implementation. In Oxford Research Encyclopedia of Natural Hazard Science.
Hanna, C., White, I., Glavovic, B., 2020. The uncertainty contagion: revealing the interrelated, cascading uncertainties of managed retreat. Sustainability 12 (2), 736.
Hanna, C., White, I., Glavovic, B.C., 2021. Managed retreats by whom and how? Identifying and delineating governance modalities. Clim. Risk Manage. 31, 100278. https://doi.org/10.1016/j.crm.2021.100278.
Hazelden, J., Hazelden, J., Boorman, L.A., 2001. Soils and 'managed retreat'in South East England. Soil Use Manag. 17 (3), 150–154.
Healy, T., Soomere, T., 2008. Managed retreat—is it really an option for mitigation of chronic erosion and storm surge flooding? In Solutions to Coastal Disasters 2008 (pp. 456-462).
Hino, M., Field, C.B., Mach, K.J., 2017. Managed retreat as a response to natural hazard risk. Nat. Clim. Change 7 (5), 364–370.
Hjort, J., Karjalainen, O., Aalto, J., Westermann, S., Romanovsky, V., Nelson, F., Etzelmüller, B., Luoto, M. 2018. Degrading permafrost puts Arctic infrastructure at risk by mid-century. Nature Communications, 2018; 9 (1) doi: 10.1038/s41467-018-07557-4.
Intergovernmental Panel on Climate Change (IPCC) (2018). Summary for Policymakers. In: Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty.
Peter Byrne, J., Grannis, J., 2012. "Coastal Retreat Measures", chapter 9. In: Gerrard, M.B., Kuh, K.F. (Eds.), The Law of Adaptation to Climate Change, 283. American Bar Association.
Jagai, J.S., Li, Q., Wang, S., Messier, K.P., Wade, T.J., Hilborn, E.D., 2015. Extreme precipitation and emergency room visits for gastrointestinal illness in areas with and without combined sewer systems: an analysis of Massachusetts data, 2003–2007. Environ. Health Perspect. 123 (9), 873–879.
Jeffery, M., Vaughati, M., 1993. St. & Regional Comprehensive Plan, Implementing New Methods Growth Mgmt., Chapter 9: Toward Environmentally Sound Planning and Development in Ontario. American Bar Association, 1993.
Jones, S., Ruppert, T., Deadey, E., Payne, H., Pippin, J., Huang, L., Evans, J., Roads to Nowhere in Four States: State and Local Governments in the Atlantic Southeast Facing Sea-Level Rise. 44 Columbia Journal of Environmental Law 67 (2019). https://www.flseagrant.org/wp-content/uploads/Jones-et-al_Roads-to-Nowhere_Vol.44.1.pdf.
Jonkeren, O., Rietveld, P., van Ommeren, J., Te Linde, A., 2014. Climate change and economic consequences for inland waterway transport in Europe. Reg. Environ. Change 14 (3), 953–965.
Klein, R.J.T., Bateman, I.J., 1998. The recreational value of Cley Marshes nature reserve: an argument against managed retreat? Water Environ. J. 12 (4), 280–285.
Koetse, M.J., Rietveld, P., 2009. The impact of climate change and weather on transport: An overview of empirical findings. Transp. Res. Part D: Transp. Environ. 14 (3), 205–221.
Koraim, A.S., Heikal, E.M., Abozaid, A.A., 2011. Different methods used for protecting coasts from sea level rise caused by climate change. Current Development in Oceanography 3 (1), 33–66.
Kool, R., Lawrence, J., Drews, M., Bell, R., 2020. Preparing for sea-level rise through adaptive managed retreat of a New Zealand stormwater and wastewater network. Infrastructures 5 (11), 92.
Koslov, L., 2016. The case for retreat. Public Culture 28 (2 79), 359–387.
Kousky, C., 2014. Managing shoreline retreat: a US perspective. Clim. Change 124 (1-2), 9–20.
Krolik-Root, C., Stansbury, D.L., Burnside, N.G., 2015. Effective LiDAR-based modelling and visualisation of managed retreat scenarios for coastal planning: An example from the southern UK. Ocean Coast. Manag. 114, 164–174.
Larsen, P.H., Goldsmith, S., Smith, O., Wilson, M.L., Strzepek, K., Chinowsky, P., Saylor, B., 2008. Estimating future costs for Alaska public infrastructure at risk from climate change. Global Environ. Change 18 (3), 442–457.
Lawrence, J., Boston, J., Bell, R., Olufson, S., Kool, R., Hardcastle, M., Stroombergen, A., 2020. Implementing pre-emptive managed retreat: constraints and novel insights. Curr. Climate Change Rep. 6 (3), 66–80.
Linnenluecke, M.K., Stathakis, A., Griffiths, A., 2011. Firm relocation as adaptive response to climate change and weather extremes. Global Environ. Change 21 (1), 123–133.

Loeb, P., 2017. This Flood-Savaged Hamlet Proves Climate Change Isn't Just a Coastal Concern. Pocket, September 5, 2017, available at https://getpocket.com/explore/item/this-flood-savaged-hamlet-proves-climate-change-isn-t-just-a-coastal-concern?utm_source=pocket-newtab, accessed May 25, 2021.
Louisiana Office of Community Development, 2020. Resettlement of Isle de Jean Charles, available at http://isledejeancharles.la.gov/sites/default/files/public/IDJC-Background-and-Overview-6-20_web.pdf.
Mach, K.J., Kraan, C.M., Hino, M., Siders, A.R., Johnston, E.M., Field, C.B., 2019. Managed retreat through voluntary buyouts of flood-prone properties. Sci. Adv. 5 (10), eaax8995. https://doi.org/10.1126/sciadv.aax8995.
Maldonado, J. K., Shearer, C., Bronen, R., Peterson, K., Lazrus, H., 2013. The impact of climate change on tribal communities in the US: displacement, relocation, and human rights. In Climate change and indigenous peoples in the United States (pp. 93-106). Springer.
Metropolitan Government of Nashville, 2011. Severe Flooding May 2010, After Action Report/Improvement Plan, July 6, 2011.
Nash, W., Bush, D., Pilkey, O., 2005. In: Encyclopedia of Coastal Science. Springer, The Neterlands, pp. 602–606.
National Flood Insurance Program, 2019. 42 U.S.C. § 4026 (2019).
Neal, W.J., Bush, D.M., Pilkey, O.H., 2005. Managed retreat. Encycl. Coastal Sci. 602–606.
Nguyen, Cuong. Homeowners' choice when the government proposes a managed retreat. Int. J. Disaster Risk Reduction (2020): 101543.
NSF, n.d. National Flood Services, "The Overlooked Inland Flooding Consequences of Climate Change.", available at https://nationalfloodservices.com/blog/the-overlooked-inland-flooding-consequences-of-climate-change/, accessed May 8, 2021.
Olsen, J.R., Zepp, L.J., Dager, C.A., 2005. Climate impacts on inland navigation. In: Impacts of Global Climate Change (pp. 1-8).
Olufson, S., 2019. Managed Retreat Components and Costing in a Coastal Setting.
Osman, P., 2017, December. The Two Edged Sword; Illinois' Risk Reduction Success through Managed Retreat And Strong Regulations. In 2017AGU Fall Meeting Abstracts. AGU.
Pinter, N., Dalbom, C., 2017, December. Mitigating Flood Risk and Climate Change Impacts through Managed Retreat. In 2017 AGU Fall Meeting Abstracts. AGU.
Plastrik, P., Cleveland, J., 2019. Can It Happen Here? Improving the Prospect for Managed Retreat by Us Cities. Innovation Network for Communities, Summit Foundation.
Repanshek, K., 2007. Park History: How the National Seashores Came to Be. National Parks Traveler, Nov. 27, 2007, available at https://www.nationalparkstraveler.org/2007/11/park-history-how-national-seashores-came-be2174#:~:text=Established%20in%201971%2C%20the%20135%2C600,the%20country's%20largest%20national%20seashore. Accessed May 27, 2021.
Rogers, K., Saintilan, N., Copeland, C., 2014. Managed retreat of saline coastal wetlands: challenges and opportunities identified from the Hunter River Estuary, Australia. Estuaries and Coasts 37 (1), 67–78.
Rott, N., "Retreat is not an Option as a California Beach Town Plans for Rising Seas.", Dec. 4, 2018, NPR, https://www.npr.org/2018/12/04/672285546/retreat-is-not-an-option-as-a-california-beach-town-plans-for-rising-seas.
Rulleau, B., Rey-Valette, H., 2017. Forward planning to maintain the attractiveness of coastal areas: Choosing between seawalls and managed retreat. Environ. Sci. Policy 72, 12–19.
Ruppert, T., Grimm, C., November 2013. Drowning in Place: Local Government Costs and Liabilities for Flooding Due to Sea-level Rise. 87 Florida Bar Journal 9.
Ruppert, T. Castles and Roads in the Sand: Do all Roads Lead to a Taking? Environmental Law Reporter, October 2018, Vol. 48, No. 10.
Rush, Elizabeth, Rising: Dispatches from the New American Shore. Milkweed Editions, 2019.
Rutledge, A., 2018. Climate Change adaptation in Metro Vancouver: examining the role of managed retreat. Thesis, University of Waterloo, available at https://uwspace.uwaterloo.ca/bitstream/handle/10012/12939/Rutledge_Alexandra.pdf?sequence=3&isAllowed=y.
Sellers, F., "Amid flooding and rising sea levels, residents of one barrier island wonder if it's time to retreat," Washington Post, Nov. 9, 2019. https://www.washingtonpost.com/national/how-do-we-continue-to-have-life-here-amid-flooding-and-rising-sea-levels-residents-of-one-barrier-island-wonder-if-its-time-to-retreat/2019/11/09/dff076c0-fcab-11e9-ac8c-8eced29ca6ef_story.html.
Siders, A., 2013. Managed Coastal Retreat: A Legal Handbook on Shifting Development Away from Vulnerable Areas. Columbia Public Law Research Paper, pp. 14–365.
Siders, A.R., 2019a. Social justice implications of US managed retreat buyout programs. Clim. Change 152 (2), 239–257.
Siders, A.R., 2019b. Managed Retreat in the United States. One Earth 1 (2), 216–225. https://doi.org/10.1016/j.oneear.2019.09.008.
Siders, A.R., Hino, M., Mach, K.J., 2019. The case for strategic and managed climate retreat. Science 365 (6455), 761–763.
Scott, M., Lennon, M., Tubridy, D., Marchman, P., Siders, A.R., Main, K.L., Johnson, C., 2020. Climate disruption and planning: resistance or retreat? Planning Theory & Practice 21 (1), 125–154.
State of Hawaii, 2019. Office of Planning, Coastal Zone Management Program. Assessing the Feasibility and Implications of Managed Retreat Strategies for Vulnerable Coastal Areas in Hawaii, Final Report, 2019. Available July 5, 2020 at http://files.hawaii.gov/dbedt/op/czm/ormp/assessing_the_feasibility_and_implications_of_managed_retreat_strategies_for_vulnerable_coastal_areas_in_hawaii.pdf.
Townend, I., Pethick, J., 2002. Estuarine flooding and managed retreat. Philosophical Transactions of the Royal Society of London. Series A: Mathematical, Physical and Engineering Sciences, 360(1796), 1477-1495.
United Nations Framework Convention on Climate Change (UNFCCC), no date. Climate Change Lexicon, Acronyms and Terms, available July 6, 2020 at https://unfccc.int/fr/processus-et-reunions/la-convention/lexique-des-changements-climatiques-acronymes-et-termes#a.
United Nations Framework Convention on Climate Change (UNFCCC). (1992). United Nations Treaty Series, vol. 1771, p. 107.
United States Department of Transportation (U.S. DOT), 1994. Environmental Advantages of Inland Barge Transportation, Maritime Administration, Final Report.
Van Alstyne III, L., 2015. Changing Winds and Rising Tides on Beach Renourishment in Florida: Short-Term Alternatives and Long-Term Sustainable Solutions Using Law and Policy from Florida and Nearby States. Fla. A & M UL Rev., 11, 283.
World Bank, 2020. Critical Funds for Tuvalu's Aviation Sector Approved. World Bank press release, November 16, 2017.
Zheng, Y., Kim, A.M., 2017. Rethinking business-as-usual: Mackenzie River freight transport in the context of climate change impacts in northern Canada. Transp. Res. Part D: Transp. Environ. 53, 276–289.
Zhou, Q., Su, J., Leng, G., Peng, J., 2019. The role of hazard and vulnerability in modulating economic damages of inland floods in the united states using a survey-based dataset. Sustainability 11 (13), 3754.