

COASTAL HAZARD MITIGATION AND ADAPTATION
IN NORTH AMERICAN COASTAL SETTLEMENTS

A Thesis

by

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ABSTRACT

Frequency and intensity of coastal hazards driven by climate and land change have been increasing in many parts of the world, including in North America, where 40% of the population lives near the coast. While many settlements are mandated to have hazard mitigation plans, the extent to which these plans address emerging vulnerabilities of these settlements to coastal hazards is unclear. To assess the main factors affecting coastal hazard mitigation and adaptation in North American coastal cities, we carried out a systematic review of the coastal hazard mitigation literature to assess how mitigating natural hazards has been studied in the literature. We identified 67 papers that specifically studied how and why hazard mitigation planning aided or hindered mitigation in 140 locations vulnerable to coastal hazards. Case studies situated in the United States account for nearly 90% of all case studies in this review. The themes of institutional capacity, implications for stakeholders and infrastructure, and attitudes toward resettlement are threaded through the 67 selected articles. We grouped papers in our review according to the type of coastal hazards they considered, namely, Sea Level Rise, Environmental Change, Extreme Weather, and Tsunami. While no case study location was studied in all four categories, 31 settlements across the United States and Canada were studied in the context of sea level rise, environmental change, and extreme weather, and one state – Alaska – was studied in the context of the three categories of sea level rise, environmental change, and tsunami. Of the locations in this review, Alaska, Louisiana, and Florida are the states most studied among state-wide case studies, while the most studied settlements are Kivalina, Alaska, and New York City, New York. The literature indicates that better interagency and scientific communication with the public as well as improved governance frameworks for adaptation and mitigation, including

resettlement, can serve to minimize stakeholders' climate science mistrust and to promote the rise of local leaders for local mitigation strategies and greater environmental equity in both urban and rural coastal communities.

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1. INTRODUCTION

Coasts globally are becoming more exposed to hazards as a result of global climate change, which is driving sea level rise as well as an increase in the frequency and intensity of coastal hazards worldwide (Albert, Bronen et al. 2018). Forty percent of the North American population lives on the coast (Manson, Solomon et al. 2005, Kauneckis and Martin 2020), and that percentage is expected to rise (Neumann, Vafeidis et al. 2015). In the United States, population at risk to sea level rise of either 0.9 m or 1.8 m is expected to double from 2010 to 2100 (Hauer, Evans et al. 2016). One study across all United States coastal counties found sea level rise to be the single greatest indicator of the overall vulnerability of the coastal communities (Boruff, Emrich et al. 2005). Coastal communities are thus among the most vulnerable to weather-related disasters worldwide and must seek to maximize their resilience in order to minimize environmental and social consequences (Adger, Hughes et al. 2005, Wilson, Kelly et al. 2017, Norton, Buckman et al. 2019). Along with people, infrastructure along the coastline is increasingly exposed to coastal hazards, necessitating that coastal communities take preemptive action to mitigate increasingly frequent and costly hazards (Bai, Surveyer et al. 2016).

Preemptive action can take the form of structural and non-structural mitigation measures. Structural mitigation is the use of physical construction and engineering to reduce hazard impacts, including coastal armoring, dikes, and flood levies (Doberstein, Tadgell et al. 2020). Non-structural mitigation is the use of policy and education to reduce hazard risks and impacts such as through building codes and training programs (Joffe, Perez-Fuentes et al. 2016). Beyond structural and non-structural mitigation, coastal settlements may benefit from ecosystem services

that can serve to reduce coastal hazard impacts, such as wetlands that provide a buffer to storm surge as well as other forms of flood regulation (Arkema, Guannel et al. 2013). Further, if the mitigation strategies of protection and accommodation fail, coastal settlements may be forced to retreat from the water's encroaching edge (Griggs 2015). However, even in North America, a developed region, the degree to which coastal settlements are prepared to mitigate and adapt to increased hazard exposure varies widely from community to community across the region.

Canada launched a federal National Disaster Mitigation Strategy in 2008 to promote mitigation as a collaborative effort among federal, provincial, and territorial governments and community-based partnerships (Canada 2008). However, in the United States, there is no federal mandate that settlements establish hazard mitigation plans (Masterson, Peacock et al. 2014). While settlements are incentivized through the United States Disaster Mitigation Act of 2000 to create hazard mitigation plans, some settlements' hazard mitigation plans can counterproductively serve to increase vulnerability to hazard (Berke, Malecha et al. 2018). Furthermore, hazard mitigation plans do not necessarily address emerging hazards. As a result, many North American coastal settlements are underprepared for current and future impacts of global climate change, impacting safety of communities. Our study assesses the main factors affecting coastal hazard mitigation and adaptation in North American coastal settlements.

2. COASTAL HAZARD MITIGATION AND ADAPTATION IN NORTH AMERICAN COASTAL SETTLEMENTS

2.1. Introduction

Approximately one-third of the world's population lives within 100 kilometers of the coastline today (Bukvic, Rohat et al. 2020), with 10% of the global population living 10 meters or less above sea level in the low elevation coastal zone (Bronen and Chapin 2013). By percentage, North American coasts are populated even more: Approximately 40% of the United States population lives in coastal counties (Kauneckis and Martin 2020); of the United States' 25 most populous counties, 23 counties are coastal (Arkema, Guannel et al. 2013). In Canada, nearly 40% of the population lives within 20 kilometers of the coast (Manson, Solomon et al. 2005). It is expected that the percentage of people living in the low elevation coastal zone of the North American coast will increase 40% from 2000 to 2030 (Neumann, Vafeidis et al. 2015) while North American coastal urban land will nearly double from 12,250 km² in 2000 to 21,400 km² by 2030 (Güneralp, Güneralp et al. 2015).

In the United States, the Disaster Mitigation Act of 2000 encourages settlements to have hazard mitigation plans in exchange for federal funding for those mitigation activities (Masterson, Peacock et al. 2014). While these hazard mitigation plans have to meet federal standards in order to gain funding (Stevens and Shoubridge 2014), the extent to which these plans address emerging vulnerabilities of these settlements to coastal hazards is unclear. What are the most important factors that influence mitigation against hazards in North American coastal settlements? To address this question, we carried out a systematic review of the coastal hazard mitigation literature.

2.2. Methods

We systematically reviewed the peer-reviewed scientific literature for studies that assess coastal mitigation in the face of hazards or global environmental change. We searched in the Web of Science (WoS) database for peer-reviewed articles regarding North American coastal settlements, hazards, and hazard mitigation. We searched by topic all years in WoS, namely, articles published from 1900 until July 2020. The full search string is available in the Appendix, Section A.1. We used the following criteria to account for article eligibility to include in the review:

- A. Language: The primary language of the article must be English.
- B. Document type: The document must have been published in a peer-reviewed journal. Conference proceedings and book sections were excluded from this study.
- C. Originality: Review articles or commentary, correspondences, or letters were excluded from this study.
- D. Publication date: All the studies published and available online by July 31, 2020 were considered for this study.
- E. Topic: Articles that included hazard mitigation planning in North American coastal communities with input from stakeholders, either in the form of participation in planning or as sharing perceptions of hazards or hazard mitigation planning, were considered for this study.

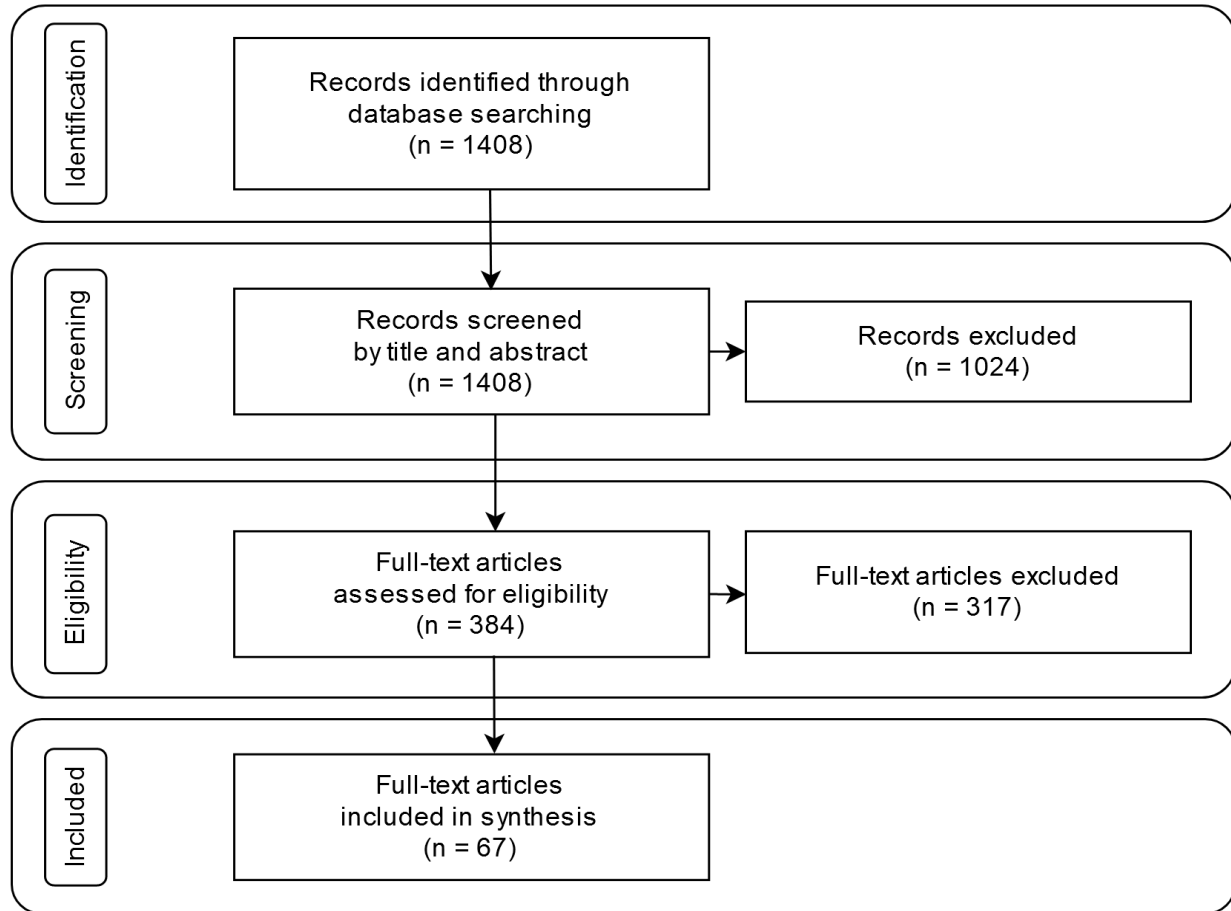


Figure 2.1. PRISMA work flow diagram depicting literature search and evaluation for inclusion. The 67 retained articles contain 140 case studies. Adapted from Moher et al. 2009.

The initial search yielded 1408 results (Figure 2.1). Five documents were excluded based on document type and language, and a further 1336 articles - of which 1019 were screened based on title and abstract and 317 were screened based on the article's full text - were excluded based on topic and location. Only if the article contained 1) hazard mitigation planning in a North American coastal settlement and 2) community stakeholder – either official or public – participation was the article considered suitable for this synthesis. Hazard mitigation planning scenarios proposed or studies by the authors without indication of community participation or buy-in were excluded. Both the title and abstract and full text screenings were done only by the

principal reviewer. In the end, 67 articles were retained for analysis. To extract data for analysis, we developed a coding sheet based on the themes emerging from the retained literature.

2.3. Results

We grouped papers in our review according to the type of coastal hazards they considered (Figure 2.2). The coastal hazards considered can be grouped broadly into four categories: Sea Level Rise (Figure 2.3 A), Environmental Change (Figure 2.3 B), Extreme Weather (Figure 2.3 C), and Tsunami (Figure 2.3 D). Studies of sea level rise (Figure 2.3 A) were conducted at either the state level or the city/county level in all coastal states in the United States except Mississippi, and were conducted at both levels in a majority of coastal US states. City/County-level studies are clustered in the Pacific Northwest (Washington and Oregon) and in the New Jersey – Maryland – Virginia area. Studies of environmental change (Figure 2.3 B) took place primarily at the city/county level, Alaska being the sole state to have been studied at the state-level. There is a cluster of city/county-level studies of environmental change in the New Jersey – Maryland – Virginia area, in Oregon, and in Nova Scotia (Canada). Statewide studies of extreme weather (Figure 2.3 C) took place primarily in the southeastern United States, whereas city/county-wide studies are clustered in the Pacific Northwest (Oregon, Washington, and southwestern British Columbia), along the Gulf Coast (Louisiana, Mississippi, and Alabama), and in the New Jersey – Maryland – Virginia area. Studies of tsunami (Figure 2.3 D) are clustered along the western edges of the United States, including statewide studies of all Pacific US states, a cluster of city/county-level studies in the Pacific Northwest (Oregon and Washington), and two settlements along the western coast of Florida. No city or county or state was studied in all four categories. However, 31 settlements – including four locations in Alaska, six locations in Oregon, and four

locations in Canada as well as several major cities such as Baltimore, Maryland, Philadelphia, Pennsylvania, Seattle, Washington, and Los Angeles, San Diego, and San Francisco, California – but no states were studied in the categories of sea level rise, environmental change, and extreme weather. Alaska was the only state studied in three hazard categories, namely, in the categories of sea level rise, environmental change, and tsunami.

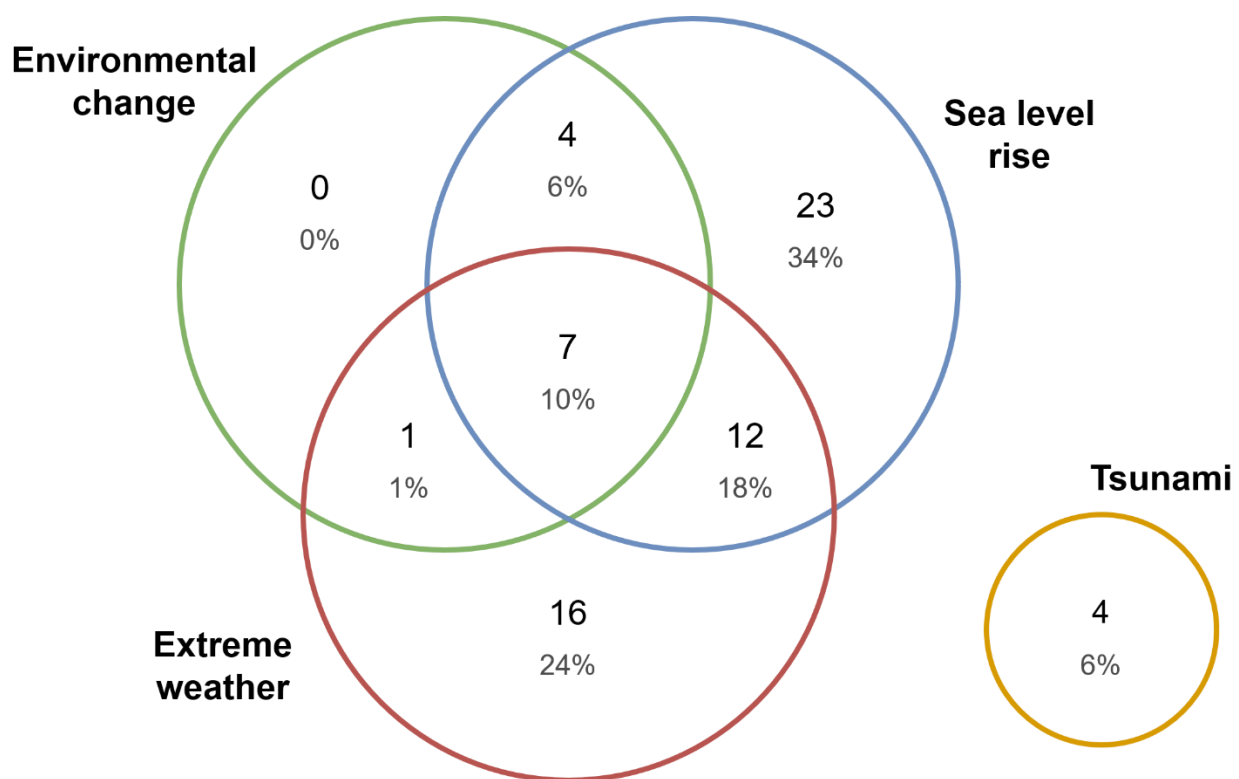
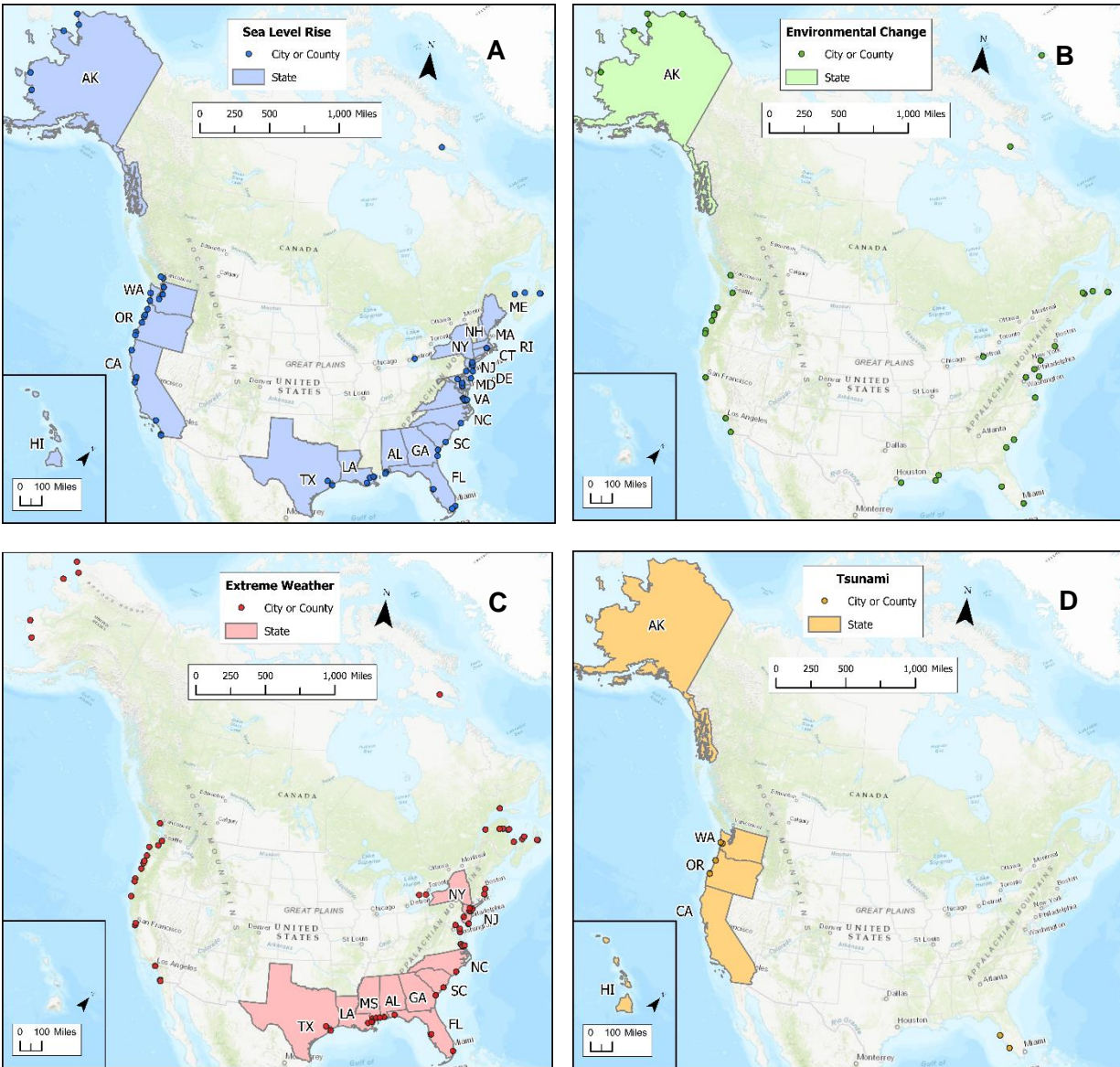


Figure 2.2. Distribution of coastal hazards across all articles.



Figures 2.3. Case studies grouped by major hazard categories: Sea Level Rise (A), Environmental Change (B), Extreme Weather (C), and Tsunami (D).

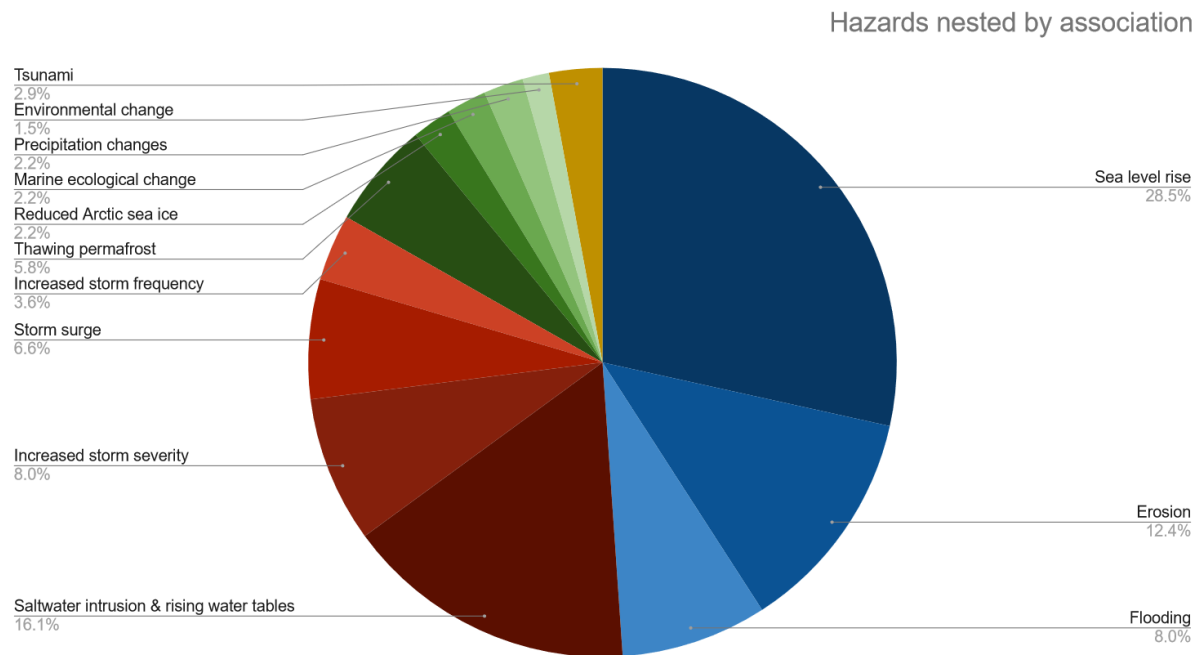


Figure 2.4. Subcategories of coastal hazards across all articles. Article count does not add up to 67, as a number of papers in our review consider more than one hazard.

We then further grouped the papers according to the specific hazard in each of the four categories (Figure 2.4). Sea level rise, including erosion and flooding in the context of sea level rise, is the coastal hazard of interest in over half of the papers, while a third discussed issues related to extreme weather events, such as hurricanes and storms and increased storm severity and frequency. Forty papers considered only one hazard, 4 papers considered 2 hazards, 10 papers considered 3 hazards, 6 papers considered 4 and 5 hazards each, and 1 paper considered 6 hazards. Forty reviewed articles discuss sea level rise (shades of blue), of which 18 and 11, respectively, discussed specifically erosion and flooding in the context of sea level rise. Among the category of extreme weather events (shades of red), 22 articles discuss hurricanes and storms, 11 discuss increased storm severity, 9 storm surge, and 5 increased storm frequency. Under environmental change (shades of green), 9 articles discuss thawing permafrost, 3 articles discuss

reduced Arctic sea ice, 3 articles discuss marine ecological change, 3 articles discuss weather variability in the form of precipitation changes, and 2 environmental change. Four articles discuss tsunami (orange).

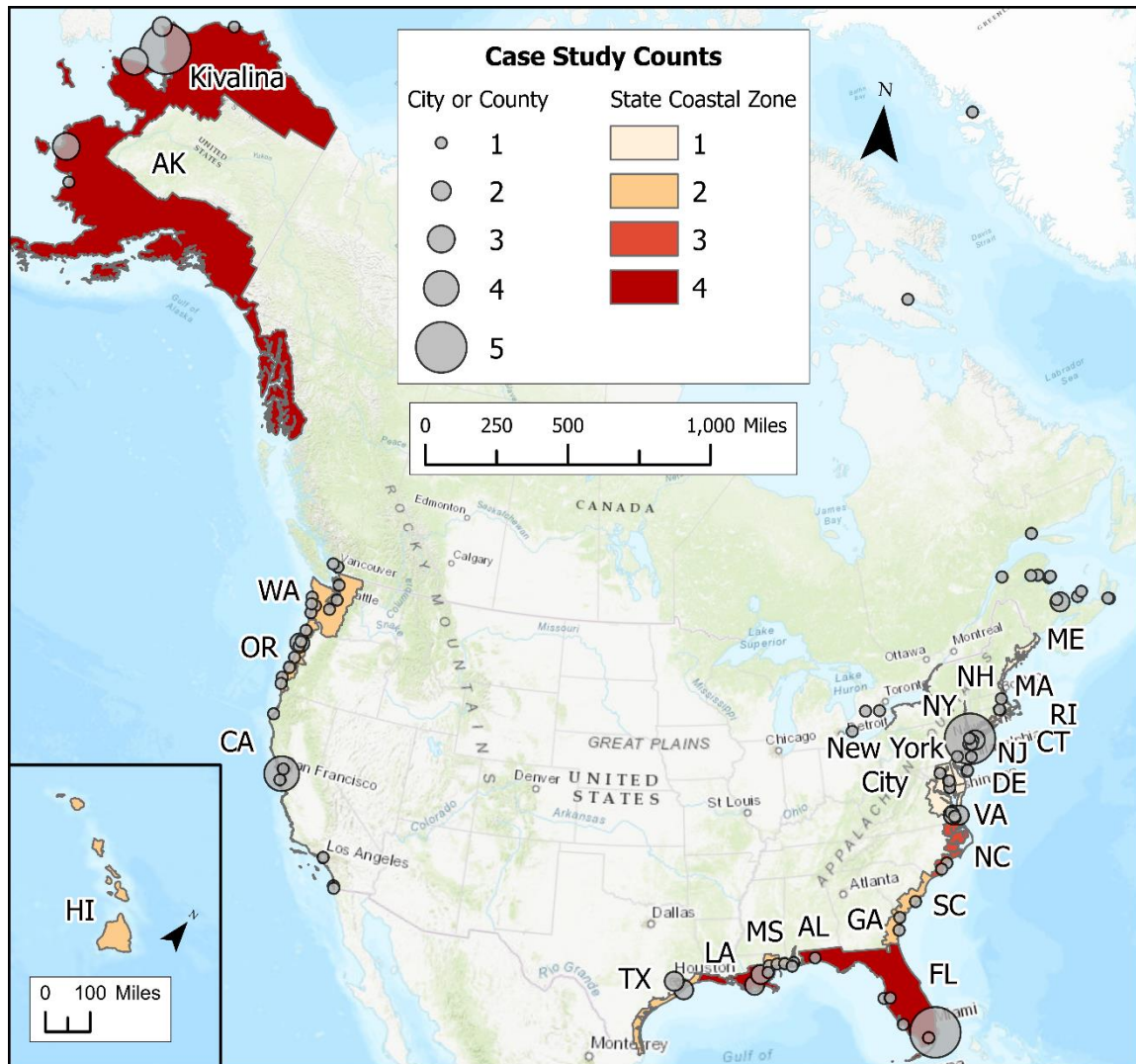


Figure 2.5. Case study locations for the 140 case studies in the 67 reviewed articles. Multi-location studies are depicted by each location. National surveys are not depicted. Coastal land depicted for state coastal zone is of the Coastal Zone Management Program of the United States, including Alaska before the state withdrew from the program.

In North America, the United States is the most studied country (123 case studies), then

Canada (16) and Greenland (1). Among state-wide case studies, Alaska, Louisiana, and Florida appear most frequently (4 articles each), while Kivalina, Alaska, and New York City, New York, are the most studied individual settlements (5 articles each) (Figure 2.5). Alaska has the largest number of city- or county-level case study locations (15 studies) followed by Florida and Oregon (12 studies each). Combining both city/county- and state-level case studies, Alaska (19 studies) and Florida (16 studies) are the most studied states whereas Maine and New Hampshire are the least studied (1 state-wide study each). There are no province-wide studies from Canada. Nearly half of the articles discuss factors related to both physical and social vulnerability (n=28); 40% (n=26) of the articles primarily discuss factors related to physical vulnerability, and only 9 articles discuss primarily social vulnerability. While the oldest article included in our review was published in 2002, most were published between 2015 and 2020, with between 4 and 10 publications per year (see Figure A.1. for the full distribution of publication years). Journals with the highest number of publications in this review are *Climatic Change* (5 publications) and *Natural Hazards* (4 publications) (see Table A.1. for the full list of journals in which papers in our review are published).

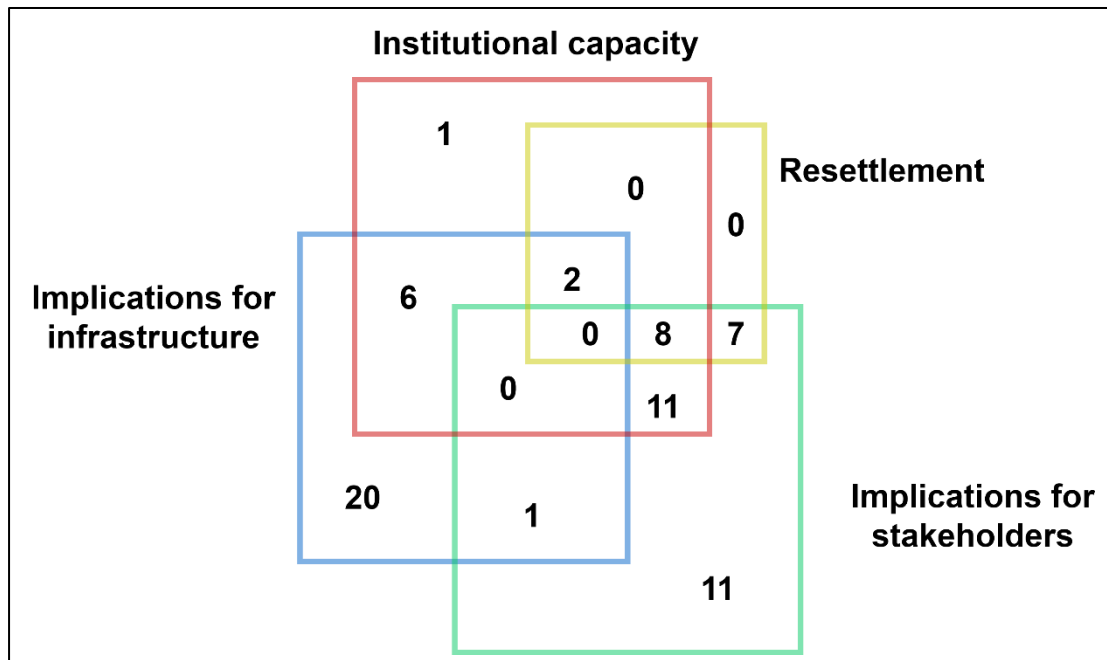


Figure 2.6. Modified Venn diagram of the thematic intersections among the 67 articles.

We also sorted articles based on their thematic focus (Figure 2.6). In addition to institutions, stakeholders, infrastructure, we included resettlement as one of the four themes as a particularly consequential form of adaptation for coastal settlements (see Figures 2.7-10 for the spatial distribution of each theme). Thirty-two papers had a single thematic focus while the rest focused on two or more themes. Of the 67 articles, 57% (n=38) focus on impacts on stakeholders and 42% (n=28) focus on implications for infrastructure, with one article in both categories. One article did not fit into the stakeholder/infrastructure binary, instead focusing completely on institutional capacity. Further, 42% (n=28) discuss institutional capacity and a quarter of the articles (n=17) discuss climate migration in the form of resettlement. Of the articles focusing on the impact of hazards and hazard planning on stakeholders, 12% (n=8) focus thematically on both institutional capacity and resettlement. Among the articles focusing on the impacts of hazards and hazard planning on infrastructure, 3% (n=2) focus thematically on both institutional capacity and resettlement.

Regarding relocation, while a dozen Alaskan Native villages are seeking relocation out of the 184 threatened by flooding and erosion (Bronen and Chapin 2013), the relocation literature included in our study mentions only four Alaskan Native villages – Kivalina (5 articles), Shishmaref (3 articles), Newtok (3 articles), and Quinhagak (1 article). The remaining two Indigenous case study locations seeking resettlement, namely Isle de Jean Charles, LA, and Taholah, WA., are in the contiguous United States.

Finally, 45% (n=30) of the papers in our review are comparative studies. Of these, 22 articles compare locations within North America, 5 articles compare a location in North America to one or more locations outside of North America, and 3 articles compare multiple locations within North America to at least one location outside of North America (see Section A.3. for a full list of comparative case studies).

2.4. Discussion

In our review, we identified four themes, namely, the role of institutions in hazard mitigation and adaptation, particularly at the local scale; implications for stakeholders in the form of health, stakeholder perceptions, environmental inequity, and economic cost-benefit; implications for infrastructure as well as ecological planning; and the challenges and opportunities for just and equitable relocation in the face of environmental inequity.

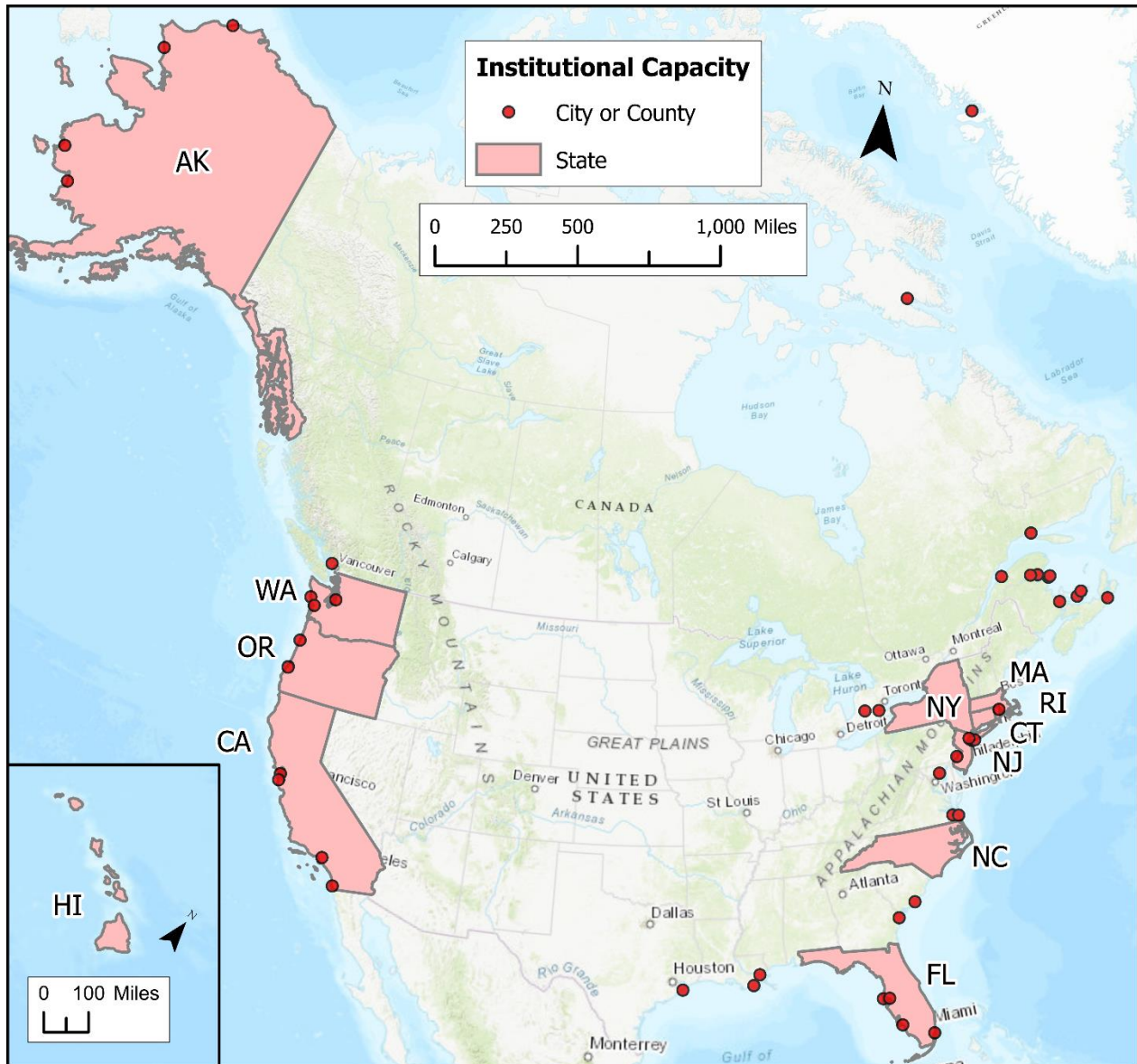


Figure 2.7. Case study locations and article counts for the 47 settlement and 12 state-wide case studies regarding institutional capacity in the 67 reviewed articles.

2.4.1 Institutional capacity

Institutional capacity in the context of hazards is the ability of an institution to set, communicate, and enforce mitigation goals and rules, and is a key component of adaptive capacity (Bronen 2015, Fu 2020). Local institutions, especially those managing collective resources, appear to better enable communities to adapt to changing hazards, underscoring a

strong theme throughout the 67 articles: that adaptation is local (Berman, Baztan et al. 2020). How the effects of climate change unfold across different geographies depends on local anthropogenic and environmental factors (Williams and Ismail 2015). Thus, adaptation to changing hazard events must similarly occur at a smaller scale to adequately respond to projected local impacts. These smaller scale adaptations, which can arise from a community's social capital, can further serve to improve a community's social capital by cultivating its components. Social capital is generated by the social networks among a community's stakeholders across multiple scales, including the household- and community-level (Nakagawa 2004, Lo, Xu et al. 2015). The components of social capital are trust in and connectedness with fellow stakeholders and community institutions, shared norms and rules, and a culture of reciprocity (Folke, Hahn et al. 2005, Berman, Baztan et al. 2020). However, social capital is not inherently beneficial. Excessive group cohesion can lead to an unwillingness to adapt, slowing or blocking community adaptation to disaster events due to community inertia or active resistance (Adger 2000, Portes 2014, Lo, Xu et al. 2015, Wilson, Kelly et al. 2017). Further, adaptations that fragment communities can weaken social capital (Dannenbergh, Frumkin et al. 2019). Thus, there can be either positive or negative feedback between adaptive capacity and social capital.

Lack of guidance and support on climate change mitigation at the federal and state levels has pushed the onus of adaptation onto local governments (Pinto, Kondolf et al. 2018, Fu 2020). For example, a 2008 study of coastal states and provinces in the United States and Canada found that over four-fifths of territories surveyed did not have a completed sea level rise adaptation plan (Carlton and Jacobson 2016). As a result, many local governments face the dual-pronged implementation dilemma of a disparity in local and national mitigation and adaptation objectives and resources, such as over land use restrictions in floodplains (Kondolf and Lopez-Llompарт

2018). While part of the disparity can arise from scale – whereby broad national objectives neglect to consider local realities (Minano, Johnson et al. 2018) – part can be attributed to the need for better interagency coordination both vertically and horizontally among different government levels and agencies (Pinto, Kondolf et al. 2018). The San Francisco Bay, for example, is managed by three federal, four state, and over 100 local agencies (Pinto, Kondolf et al. 2018). Complicated governance - both a consequence of and a perpetuator of institutional redundancy - can result in tensions among levels of government over objectives, loss of efficiency, and a lack of responsibility for adaptation efforts (Rosenzweig, Solecki et al. 2011, Nelson 2014, Pinto, Kondolf et al. 2018). For example, comparisons of Houston, Texas, to Amsterdam, the Netherlands, and of the San Francisco Bay, California, to the Tagus Estuary, Portugal (Pinto and Kondolf 2016, Kim and Newman 2019) found that the United States case study locations of Houston and the San Francisco Bay are at greater risk of sea level rise than their European counterparts due to lack of zoning and inconsistent application of legal codes, threatening urban areas in Houston and the survival of the marshes around San Francisco Bay. However, these issues can be resolved either through increased communication among involved parties or through the development of a lead agency to oversee adaptation efforts (Rosenzweig, Solecki et al. 2011, Pinto, Kondolf et al. 2018). The latter is the case in New York City, where the NYC Office of Long-term Planning and Sustainability works to coordinate the 40 member organizations of the NYC Climate Change Task Force (Rosenzweig, Solecki et al. 2011), as well as in San Mateo County, where a county-level agency works to unify government agencies addressing coastal erosion, flooding, and sea level rise (Gerrity and Phillips 2020).

Building institutional capacity through both formal and informal institutions – including community-researcher partnerships and self-governing local institutions – is particularly

important in the Arctic, where climate change has been accelerating coastal erosion, flooding, and permafrost thaw, placing coastal settlements at increasing risk (Lane, Clarke et al. 2013, Berman, Baztan et al. 2020). There is also a need for increased regional coordination, especially across functional boundaries such as watersheds rather than across administrative ones (Considine and Steinhilber 2018). For example, despite sharing the same peninsula, environmental stakeholders on either coast of the peninsula in San Mateo County, California, lacked knowledge about the hazard issues such as sea level rise and erosion that their neighbors faced due to lack of communication across municipal boundaries (Gerrity and Phillips 2020). Yet, a comparison of hazard mitigation plans across 15 coastal cities in the United States found that while plan quality varied substantially in the realms of plan updating and the identification of implementation agencies, timetables, and funding sources, the most effective plans were supported through the state and by local leadership (Fu, Gomaa et al. 2017). Better regional efforts to improve short- and long-term adaptation in the form of education, cohesive legal and planning standards, and enhanced governance serve to improve resilience at both the local and regional scales (Vasseur, Thornbush et al. 2017).

In the United States, beyond the need for greater governmental communication, there is a lack of funding for proactive mitigation for local governments from the federal government (Maldonado, Shearer et al. 2013). Climate change adaptation can in some cases attract government funding, such as New York City's sustainability plan, PlaNYC, which was developed in part to combat local sea level rise (Rosenzweig, Solecki et al. 2011). However, communities experiencing slow crises such as sea level rise or erosion are often left without funding as a result of the structure of most disaster relief programs under the Stafford Act, including FEMA, which provide funding to affected areas only following a disaster (Maldonado,

Shearer et al. 2013). As a result, many local governments rely on philanthropic sources of funding for mitigation (Finn, Chandrasekhar et al. 2019); both the Rockefeller Foundation, including its 100 Resilient Cities program, and the Riggio Foundation feature in the literature as sources of local funding (Nelson 2014, Finn, Chandrasekhar et al. 2019, Wakefield 2019). Thus, better coordination among the different levels of government and non-governmental organizations may alleviate local funding stress in the face of slow-onset disaster, especially because climate change adaptation or hazard mitigation often competes for limited funding with more short-term, immediate priorities such as economic development and the maintenance of water and sewage infrastructure (Lane, Clarke et al. 2013, Wood, Jones et al. 2014, Shilling, Vandever et al. 2016, Kauneckis and Martin 2020). In some conservative political environments, climate change may be tacitly forbidden from being discussed, further complicating funding for adaptation (Hayes, Heery et al. 2018, Finn, Chandrasekhar et al. 2019, Wakefield 2019). More commonly, however, for natural hazard risk governance to become sustainable, public participation in hazard governance needs to be strengthened from passive, one-way source of information with little decision-making power to active, empowered strategist and decisional actor in the governance process such as through the implementation of social learning, which is a collaborative knowledge-generating activity, or through stakeholder advisory boards (Boyer-Villemare, Benavente et al. 2014, Barr and Woodley 2019). While the need for active stakeholder involvement is becoming more apparent, public participation in the United States is still most often passive.

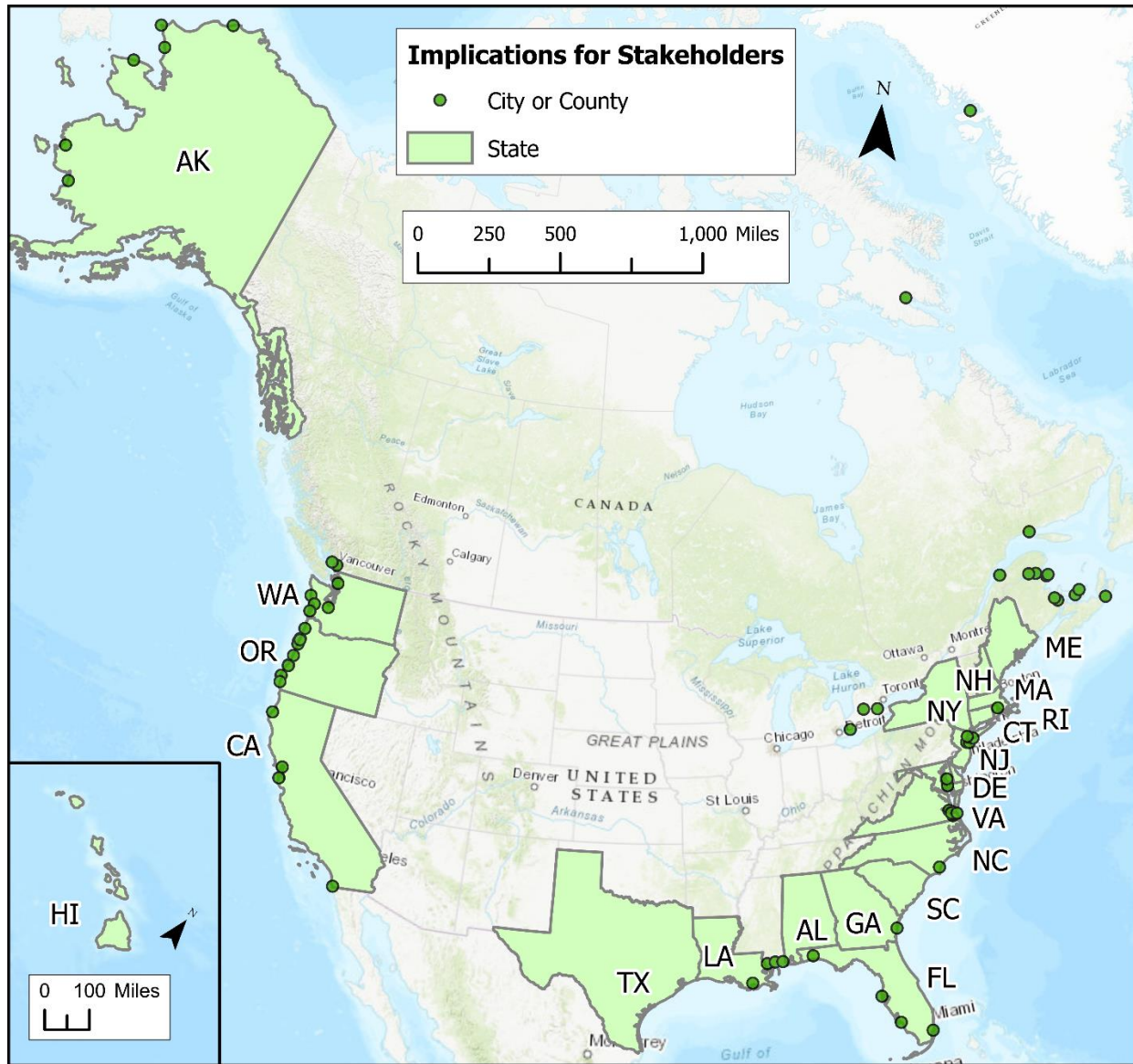


Figure 2.8. Case study locations and article counts for the 70 settlement and 21 state-wide case studies regarding implications for stakeholders in the 67 reviewed articles.

2.4.2 Implications for stakeholders

Hazard mitigation and climate adaptation planning on an individual or household level also compete with immediate priorities. Namely, individual hazard mitigation or climate adaptation is often superseded by trying to meet everyday, influenceable stressors (Carlton and Jacobson 2016), particularly in resource-dependent coastal communities despite the direct threat

of climate change (Fischer 2018). For example, while sea level rise threatens Geechee subsistence fishing in Hog Hammock, Sapelo Island, Georgia, Geechee residents report that they consider the historically contentious issues of land ownership and limited employment to be more pressing than sea level rise (Hardy, Milligan et al. 2017). Furthermore, while rural and periurban settlements and urban areas are equally willing to implement local climate adaptation (Kauneckis and Martin 2020), rural and periurban communities are typically more likely to lack the financial and institutional capacity to mitigate or adapt to hazards (Vasseur, Thornbush et al. 2017, Gerrity and Phillips 2020). In particular, communities located at a physical or cultural distance from urban institutional resources have more difficulty accessing those resources due to geographical remoteness or differences in social norms. An example of bridging these social norms is a rural outreach and education program proposed in San Mateo County, an area that includes densely populated urban areas such as South San Francisco as well as largely rural areas to the south of the county. The proposed program seeks to improve the risk perceptions of rural residents, which have been neglected in favor of more populated areas within the county (Gerrity and Phillips 2020). Nevertheless, changing natural resource availability due to climate change remains a challenge for resource-dependent communities such as settlements that rely on fishing or timber for their livelihoods, as does the lack of mitigation funding (Wood, Jones et al. 2014, Vasseur, Thornbush et al. 2017, Fischer 2018).

We also identify the lingering need for communication of scientific findings to relevant stakeholders. Both academic and non-academic stakeholders cite the disconnect between scientists and the public, including planners, as a factor in the lack of priority given to hazard mitigation and climate adaptation on both the individual/household and local government level (Lindeman, Dame et al. 2015, Shilling, Vandever et al. 2016). In one 2017 study, only a third of

resource manager participants used scientific journal articles to collect information about climate change adaptation, preferring the Internet and peers (Thorne, Elliott-Fisk et al. 2017). While opacity of scientific communication affects both urban and rural communities, better scientific and policy communication is especially needed for socially vulnerable communities (Wilson 2018). There is a need for improved education regarding adaptive behavior in the United States. A comparison of major tourist destinations Kamakura, Japan, and three cities in Florida – in which disaster prevention education is difficult due to the high transience – concluded that Florida residents were more confident but less well-informed than Kamakura residents about local hazard mitigation measures (Esteban, Bricker et al. 2018). Other forms of scientific and policy communication can be achieved through intermediary organizations such as community-based non-governmental organizations or in the form of citizens and residents as local leaders (Lane, Clarke et al. 2013, Lindeman, Dame et al. 2015, Thorne, Elliott-Fisk et al. 2017). Local leaders can serve to ‘translate’ science and policy and to champion hazard mitigation or climate adaptation policies within their communities, as did the Newtok Traditional Council regarding relocation of the Alaska Native village, Newtok (Bronen and Chapin 2013). Lack of such leadership can lead to the diffusion of responsibility among stakeholders or institutions and in a diminished perceived importance of climate change adaptation among stakeholders (Pinto, Kondolf et al. 2018). This lack of leadership can, thus, lead to institutional and personal neglect of hazard mitigation and climate adaptation.

Environmental equity concerns in the literature regarding cost-benefit analyses further speak to the disconnect between science and stakeholders. The costs and benefits of adaptation are often borne locally (Hayes, Heery et al. 2018), and so understanding and presenting those costs and benefits - including indirect costs and benefits - can be the difference between planning

and implementation from both a policy and social perspective (Peng and Song 2018). Indirect costs or benefits to adaptation may include impacts on ecosystem services, such as decreased or increased coastal environment recreation or natural resource-based productivity, or improvements in resident mental health due to lowered hazard-related stress (Brubaker, Berner et al. 2011, Neumann, Emanuel et al. 2014, Peng and Song 2018). However, traditional economic valuations such as cost-benefit analyses are too limited in scope, as the primary focus on economic impacts neglects or undermines the importance of sociocultural factors such as cultural ties to land (Maldonado, Shearer et al. 2013, Miller and Montalto 2019). Cost-benefit analyses thus neglect traditional knowledge and social equity (Fu and Song 2017, Maldonado, Collins et al. 2019). Recognizing these shortcomings of conventional cost-benefit analyses, there have been attempts in recent years to broaden the scope of cost-benefit analyses of built or natural infrastructure to include non-market social or cultural values of the environment (Ewing 2015). By providing a more holistic and accurate assessment, the incorporation of these factors would allow for more accurate evaluation of the benefits or costs of the different forms of hazard mitigation and climate adaptation. This more accurate evaluation would then include the costs to and benefits for communities that have historically been omitted from traditional cost-benefit analyses, resulting in a more equitable process.

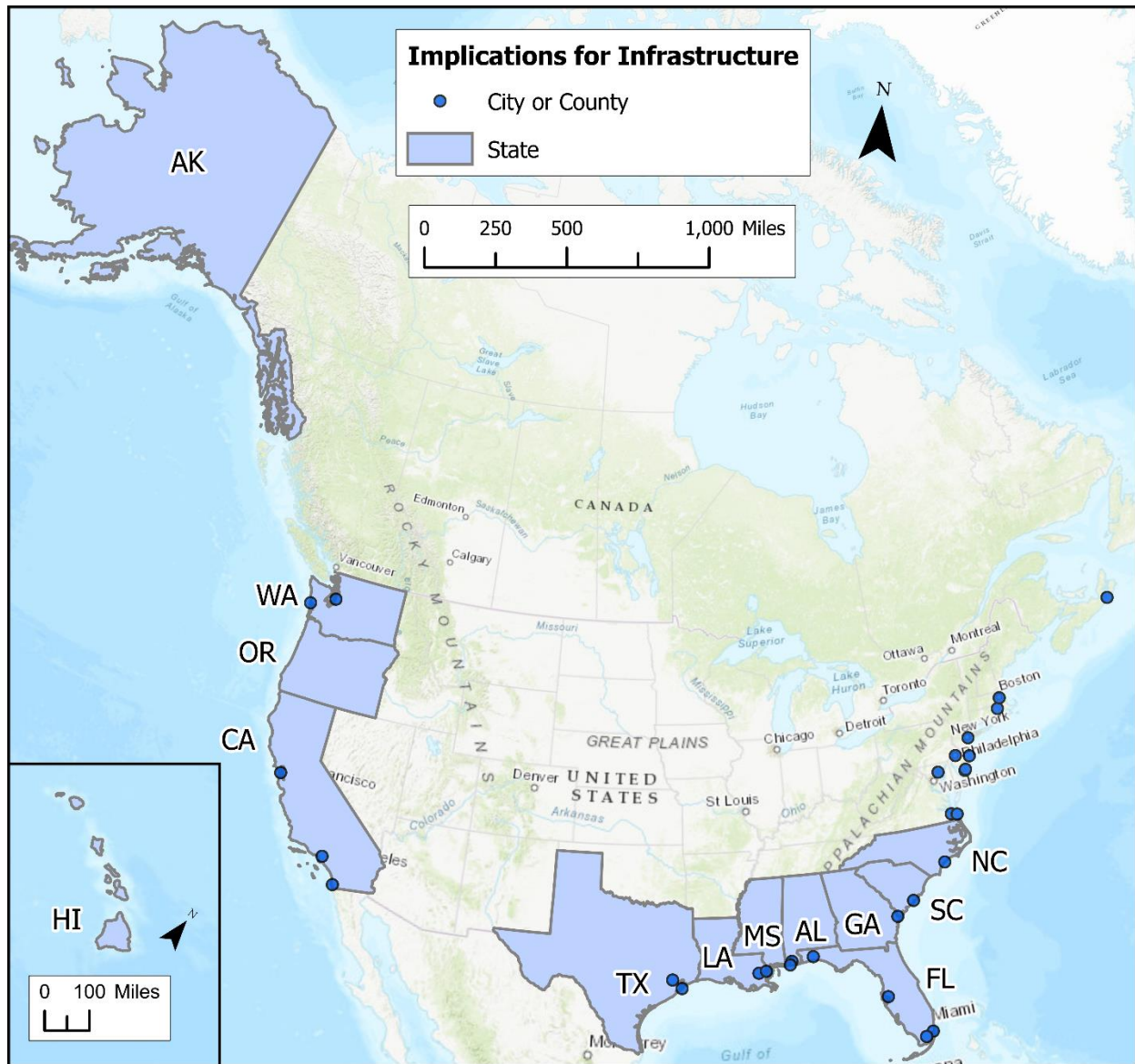


Figure 2.9. Case study locations and article counts for the 29 settlement and 13 state-wide case studies regarding implications for infrastructure in the 67 reviewed articles.

2.4.3. Implications for infrastructure

Built infrastructure can help mitigate the short-term effects of climate change (Bronen and Chapin 2013, Kirshen, Borrelli et al. 2020) while simultaneously supporting residents and economic activities. Improved shore revetment walls in northwestern Alaska not only fulfil their intended purpose in protecting infrastructure and helping slow erosion, but additionally serve to

improve local inhabitants' mental health by lowering hazard-related stress (Brubaker, Berner et al. 2011). However, the difficulty in quantifying the intangible benefits of such infrastructure means that such benefits as stress reduction and improved mental health remain unaccounted for in traditional cost-benefit analyses. Inability to accurately represent such tangible evidence in conventional cost-benefit analyses creates challenges in procuring funding for large infrastructural mitigation projects that can have both tangible benefits as protection of economic assets as well as intangible social and psychological benefits (Close, Montalto et al. 2017).

An increasing number of settlements such as Hampton Roads, Virginia, are considering mitigation and adaptation through shore-based or green infrastructural projects (Considine and Steinhilber 2018). Both grey and green infrastructure can help mitigate the effects of climate change – either separately or in conjunction. However, green infrastructure is often more cost-effective and flexible than traditional grey infrastructure, which often creates other environmental problems (Rosenzweig, Solecki et al. 2011, Pinto, Kondolf et al. 2018, Kirshen, Borrelli et al. 2020). Grey infrastructure is often difficult or prohibitively costly to remove and can hasten erosion and biodiversity loss (Vasseur, Thornbush et al. 2017) and degrade water quality (Arkema, Guannel et al. 2013) while providing only gradually diminishing benefit (Hay 2014). On the other hand, the implementation of green infrastructure can have desirable co-benefits such as the establishment of living shorelines that offer habitat and recreational opportunities as well as meeting environmental goals (Kousky 2014, Considine and Steinhilber 2018). One 2013 study suggests that green infrastructure in the form of coastal habitats currently defends 67% of the United States coast, including the most people and property in Florida, New York, and California (Arkema, Guannel et al. 2013). Regardless, grey or green infrastructure that

solely responds to current conditions without considering future hazard conditions can have limited impact on long-term resilience (Williams and Ismail 2015, Wakefield 2019).

While new infrastructure built in North America's low elevation coastal zone will be under threat of sea level rise and storm surge, North America's aging built infrastructure already is. For example, both on-land and aquatic transportation infrastructure, namely roads, railways, and ports, as well as critical infrastructure such as water, energy, communications, and sanitation infrastructure are at risk of sea level rise and increased frequency and intensity of storms (Brubaker, Berner et al. 2011, Rosenzweig, Solecki et al. 2011, Shilling, Vandever et al. 2016, Becker 2017, Bostick, Holzer et al. 2017). North Carolina residents in one study named the restoration of infrastructure – including utilities, transportation, and fire and medical services – as the most important recovery activity following a disaster (Horney, Simon et al. 2016), showcasing the need for protecting exposed critical infrastructure.

Housing is another concern. Coastal storms, particularly in conjunction with sea level rise, can flood and damage structures, including residences (Rosenzweig, Solecki et al. 2011, Bronen and Chapin 2013). One 2013 study estimates that \$300 billion of United States coastal residential property are currently highly exposed to hazards (Arkema, Guannel et al. 2013). However, not only hard (built) infrastructure is threatened. Soft infrastructure - namely, infrastructural systems such as health care services - also have personnel and built components that are at risk of increased hazards (Brubaker, Bell et al. 2011, Bronen 2015). For example, while the personnel and health supply chain of the Quinhagak, Alaska, health clinic may thus far remain uninterrupted by erosion, permafrost thaw, and storm surge, the failing structural integrity of the health clinic has placed this member of Quinhagak's soft infrastructure at risk of failure (Bronen 2015). While Quinhagak has not yet decided whether to increase protection for

the community's infrastructure or relocate elsewhere instead (Bronen 2015), considering relocation can result in loss of external investment in existing infrastructure. This was the case in Newtok, where government disinvestment following discussions of relocation forced the closure of a local power plant (Kieval 2020). Both hard and soft infrastructure necessitate upkeep and thus financial backing, and only more so in the face of changing coastal hazards. North American coastal urban land is expected to nearly double between 2000 and 2030 (Güneralp, Güneralp et al. 2015), indicating more infrastructure will be exposed to coastal hazards; thus, for the greatest increase in long-term resilience, this future infrastructure must be built and current aging infrastructure rebuilt, augmented, or relocated in response to future climate conditions.

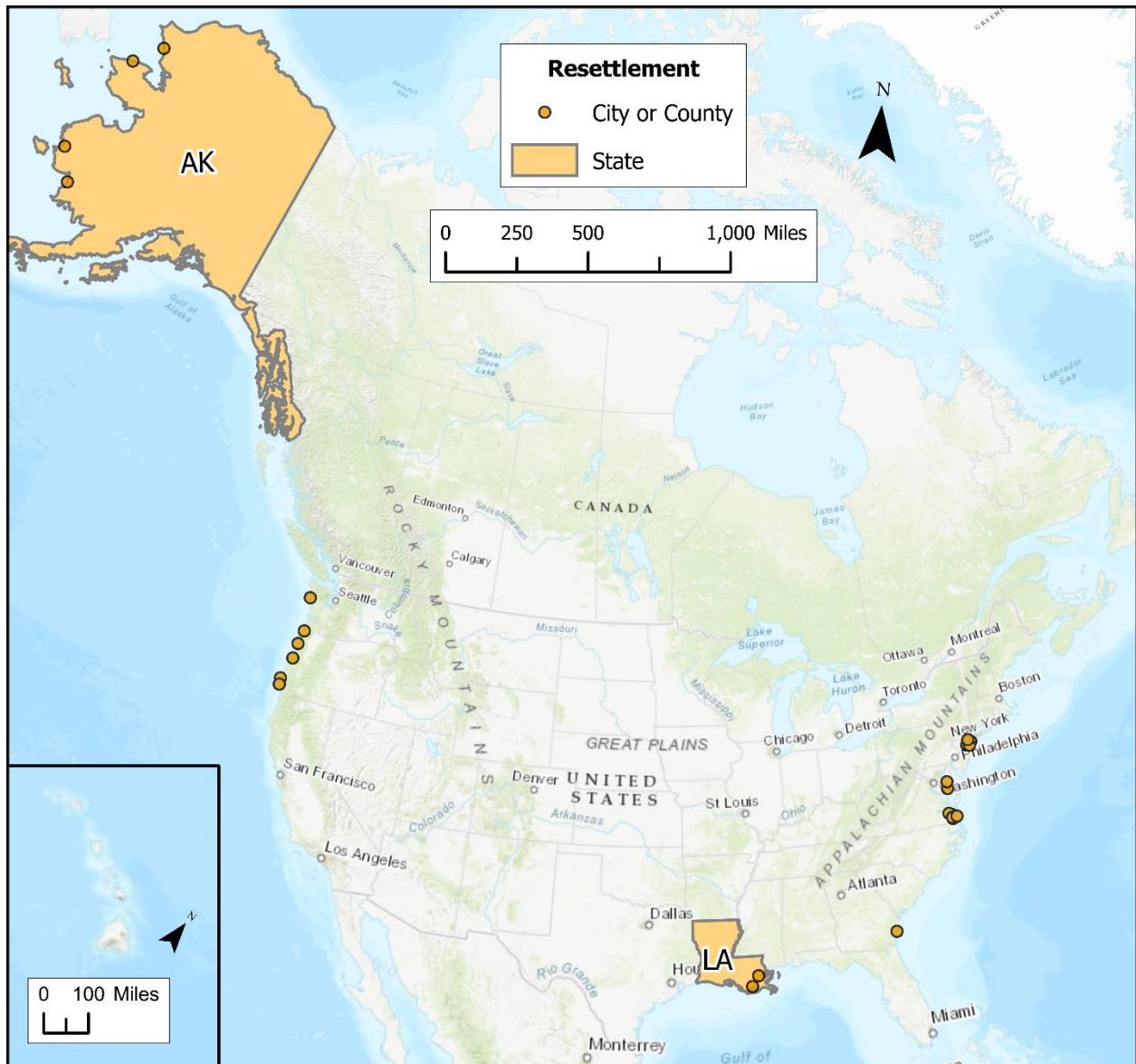


Figure 2.10. Case study locations and article counts for the 25 settlement and two state-wide relocation case studies in the 67 reviewed articles.

2.4.4. Challenges and opportunities for just and equitable resettlement

Resettlement, or relocation, occurs when inhabitants of a settlement permanently relocate in response to a hazard or a series of hazards. While this displacement is often at the household level, entire coastal communities may also consider relocation as a result of global environmental

change (Maldonado, Shearer et al. 2013). However, resettlement is often a contentious policy topic proposed by planners and officials as a last resort despite efficacy in the long term. Resettlement tends to be unpopular with stakeholders and incurs huge social, economic, and infrastructural costs in the short term compared to implementing protection and accommodation policies (Peng and Song 2018, Bukvic and Harrauld 2019, Fu 2020). Resettlement further is mired in the ethical quandary surrounding the role of the government as an assistance provider as opposed to as a decisionmaker for vulnerable populations (Wilson 2018). Furthermore, without an institutional framework to guide the relocation process, community resettlement often ends in community fragmentation as households disperse (Bronen and Chapin 2013, Albert, Bronen et al. 2018). This can result in decreased food and water security, social capital and community cohesion, and health care services, negatively impacting mental health (Dannenberg, Frumkin et al. 2019).

However, some residents choose to leave by taking advantage of buyout programs (Binder, Baker et al. 2015). These programs are implemented at the municipal, county, or state level, can be funded through federal grants, and serve as an opportunity for homeowners to sell hazardous homes – often at pre-storm value – and relocate out of areas exposed to hazard (Binder and Greer 2016, Bukvic and Harrauld 2019). While voluntary buyouts – paid for by federal funds – are thus more cost-effective for local governments than the use of locally funded eminent domain (Siders 2019), maintenance of the property is often the local government's financial responsibility (Bukvic and Harrauld 2019). Furthermore, while these programs are implemented with the hope that homeowners relocate to a less hazardous area, in one study of a buyout program in New York after Hurricane Sandy, one-fifth of households participating in the buyout relocated to an area of equal or greater flood risk (McGhee, Binder et al. 2020). There are

also equity concerns related to buyouts. These concerns often surround funding decisions regarding which communities are deemed worth protecting in place and which communities are instead relocated through buyouts (Leichenko and Thomas 2012, Bukvic and Harrauld 2019, Siders 2019). Additionally, not all communities that desire a buyout receive the opportunity: lack of government funding to buy properties at pre-storm values as well as communities with greater resources to advocate for themselves may result in communities that seek a buyout program not receiving one, such as several neighborhoods in Staten Island, New York, following Hurricane Sandy (Marino 2018, Bukvic and Harrauld 2019, Siders 2019).

One community that had the opportunity and chose to relocate in response to increasing regional hazards is Oakwood Beach, New York. The working-class residents of Oakwood Beach collectively planned to take advantage of a post-Hurricane Sandy buyout program after a series of increasing floods and fires in the area (Binder, Baker et al. 2015). Of 610 properties bought for \$240 million through the New York state buyout program, 310 homes were from Oakwood Beach (McGinty 2017). However, more often than not, community-wide relocation in the contiguous United States is not considered a viable option by stakeholders (Cleary, Willson et al. 2006, Vasseur, Thornbush et al. 2017). For example, although neighboring Oakwood Beach, the working-class community of Rockaway Park chose not to relocate following Hurricane Sandy due in part to residents' strong place-based identity (Binder, Baker et al. 2015). The Gullah Geechee of Sapelo Island, Georgia, as well as the resident of Isle de Jean Charles, Louisiana, hold similarly strong place-based ties (Hardy, Milligan et al. 2017, Dannenberg, Frumkin et al. 2019). However, ad hoc climate migration tends to strand low- and middle-income residents – particularly homeowners tied to their coastal property – in increasingly socially and financially impoverished and elderly communities (Colten, Simms et al. 2018). This happens as those who

can easily migrate from the area – the mobile young in search of employment as well as the rich, who have the financial means to do so – take with them their economic buy-in from the point of departure, leaving behind higher insurance rates and a more burdened tax base (Binder, Baker et al. 2015, Colten, Simms et al. 2018). In the case of small coastal settlements in Louisiana, for example, coastal poverty rates are increasing and those most likely to remain are older and employed in coastal resource-based work such as shrimping or fishing (Colten, Simms et al. 2018). Both sociocultural and financial factors, including the potential loss of residents' livelihoods with relocation, tie coastal residents to their increasingly hazardous homes (Dannenberg, Frumkin et al. 2019).

Relocation does not happen only through buyouts. By being available only to individual homeowners, buyouts can perpetuate the colonial principles of individualism and capitalism (Marino 2018). Buyouts therefore are not viable for collective communities such as the Iñupiat of Shishmaref, Alaska, or in locations where market value is difficult to determine such as in remote locations in Alaska (Bronen and Chapin 2013, Marino 2018). Furthermore, as many Indigenous and other minority populations have been subject to forced relocations in the past (Maldonado, Shearer et al. 2013, Hardy, Milligan et al. 2017), relocation as an adaptation activity for such communities is particularly contentious. Many Indigenous and other minority communities have endured historical trauma in the form of forced relocation, such as the forced relocation of Alaskan Aleut communities by the United States government during World War II, of First Nations people in Canada following the dispossession of their lands, or of Black Geechee residents at the hands of a white landowner in the mid-1900s in Georgia (Maldonado, Shearer et al. 2013, Hardy, Milligan et al. 2017, Colten, Simms et al. 2018). As a result, forced relocation as

an adaptation or mitigation strategy is regarded as unacceptable (Maldonado, Shearer et al. 2013).

Despite this history of forced relocation or settlement by government mandate, several - primarily Native Alaskan - settlements such as Kivalina and Newtok, Alaska, have chosen to relocate collectively in the face of increasing local hazard (Bronen and Chapin 2013, Maldonado, Shearer et al. 2013, Bronen 2015, Albert, Bronen et al. 2018, Manrique, Corral et al. 2018, Dannenberg, Frumkin et al. 2019). While all of the coastal settlements in our review that are considering relocation are facing the effects of sea level rise, including erosion, strengthened storm surge, or saltwater intrusion, many of the Native Alaskan villages such as Kivalina and Shishmaref are further threatened by thawing permafrost and reduced Arctic sea ice, rendering these settlements in particular increasingly dangerous to reside in (Bronen and Chapin 2013, Albert, Bronen et al. 2018). As a result, after over twenty years of planning, one-third of Newtok's 350 residents moved in 2019 to Mertarvik, which is located on higher ground nine miles south of Newtok on Nelson Island (Bronen 2014, Kieval 2020). The remaining residents intend to move by 2023 to a cost of over \$120 million, the funds for which took nearly two decades to assemble (Dorroh 2020). However, Newtok is an exception. By harnessing local leadership and institutional capacity – first through the Newtok Traditional Council, then later with the establishment of the Newtok Planning Group, a voluntary informal collaboration of tribal and federal governmental and non-governmental organizations (Bronen and Chapin 2013) – Newtok was able to negotiate with the U.S. Fish and Wildlife Service for the title to the land on which Mertarvik now stands (Bronen 2014). However, the lack of institutional framework or agency at the federal level in the United States to authorize and fund community relocation has placed many of the other coastal settlements seeking relocation in a limbo. Kivalina, for

example, has not been able to secure government funding from any state or federal agency (Dannenberg, Frumkin et al. 2019). Because the hazards threatening endangered settlements such as Newtok are slow-onset disasters, current governance tools such as housing assistance through FEMA or the U.S. Department of Housing and Urban Development that are activated only in the aftermath of an extreme disaster cannot be used to assist communities seeking relocation without amendment to the Stafford Act (Bronen 2015, Greer and Brokopp Binder 2016).

Furthermore, there is neither a set of best practices for buyout or other relocation program implementation nor a single centralized agency in charge of buyouts or relocation in the United States to lead funding and governance efforts (Maldonado, Shearer et al. 2013, Greer and Brokopp Binder 2016). This leaves relocation funding both difficult to source and obtain as well as overall inadequate to cover the costs – which can be range from \$20 million to \$200 million per 500 coastal residents – of relocating services or building infrastructure and housing at the new location (Maldonado, Shearer et al. 2013, Albert, Bronen et al. 2018, Dannenberg, Frumkin et al. 2019, Dorroh 2020). Due to the lack of funding coupled with the lack of institutional policy tools, many other settlements in Alaska such as Shishmaref have been working towards relocation for nearly half a century (Albert, Bronen et al. 2018). Thus, just and equitable relocation rests on the creation of an adaptive governance framework that will effectively address funding needs for the social well-being of relocated communities.

2.5. Conclusion

In our systematic review of studies on North American coastal settlements' responses to hazards they face, we find that 1) improvements to the adaptive capacity of communities and stakeholders are primarily being driven by local governments, 2) that everyday stressors often

supersede individual mitigation or adaptation, and 3) that equitable resettlement often necessitates a bottom-up approach. While the need for greater institutional capacity across all levels of governance is driven in part by the complicated governance of local adaptation, lead agencies can serve to facilitate climate adaptation and help overcome adaptation inertia, as is the case with many communities seeking to resettle. Better interagency and scientific communication to the public as well as improved governance frameworks for adaptation, including resettlement, can serve to minimize climate-science misunderstandings between academics and the public and serve to promote the rise of local leaders and greater environmental equity in both urban and rural communities. These findings should be taken into consideration by coastal settlements or stakeholders seeking to mitigate or adapt to changing hazards.

3. CONCLUSION

We undertook this systematic review of the coastal hazard mitigation literature to assess the main factors affecting coastal hazard mitigation in North American coastal settlements. To achieve this, we searched for articles that included hazard mitigation planning with regards to climate change in North American coastal communities with input from stakeholders, either in the form of participation in planning or as sharing perceptions of hazards or hazard mitigation planning. We retained and analyzed 67 articles that contained a total of 140 case studies, 123 of which were undertaken in the United States. We grouped papers in our review according to the type of coastal hazards they considered, namely, Sea Level Rise, Environmental Change, Extreme Weather, and Tsunami. No case study location was studied in all four categories, but 31 settlements across the United States and Canada were studied in the context of sea level rise, environmental change, and extreme weather, and one state – Alaska – was studied in the context of the three categories of sea level rise, environmental change, and tsunami. Alaska also has the most city/county-level case study locations and is the most studied state in state-wide studies along with Louisiana and Florida. The most studied settlements are Kivalina, Alaska, and New York City, New York. The findings from this study highlight the need for better interagency and scientific communication with the public as well as the need for improved governance frameworks for adaptation and mitigation, including frameworks for resettlement.

It is worth noting that, in this study, only peer-reviewed articles in English from a single database, Web of Science, were reviewed. The inclusion of other databases, languages, and publication types as well as a double-screening methodology could improve the evidence base from which the findings of this research are distilled.

This research assessed the main factors affecting coastal hazard mitigation and adaptation in North American coastal settlements. However, this research did not assess the hazard mitigation plans themselves to determine how well the plans are addressing future climate hazard. Future research can seek to assess coastal settlements' hazard mitigation plans directly and the degree to which those plans 1) serve to improve rather than hinder community resilience and 2) serve to address current and evolving vulnerability to global climate change.

Furthermore, no study has yet conducted a comprehensive assessment of the joint influence of local hazard mitigation plans and the existing socio-ecological system on a community's ability to respond to and recover from coastal hazards. Insight gained from such a study would be useful for developing guidelines to help coastal communities adapt to a changing global environment and develop greater resilience to flooding events induced and exacerbated by global environmental change.

REFERENCES

- Adger, W. N. (2000). "Social and ecological resilience: are they related?" Progress in Human Geography **24**(3): 347-364.
- Adger, W. N., T. P. Hughes, C. Folke, S. R. Carpenter and J. Rockström (2005). "Social-Ecological Resilience to Coastal Disasters." Science **309**: 1036-1039.
- Albert, S., R. Bronen, N. Tooler, J. Leon, D. Yee, J. Ash, D. Boseto and A. Grinham (2018). "Heading for the hills: climate-driven community relocations in the Solomon Islands and Alaska provide insight for a 1.5 degrees C future." Regional Environmental Change **18**(8): 2261-2272.
- Arkema, K. K., G. Guannel, G. Verutes, S. A. Wood, A. Guerry, M. Ruckelshaus, P. Kareiva, M. Lacayo and J. M. Silver (2013). "Coastal habitats shield people and property from sea-level rise and storms." Nature Climate Change **3**(10): 913-918.
- Bai, X., A. Surveyer, T. Elmqvist, F. W. Gatzweiler, B. Güneralp, S. Parnell, A.-H. Prieur-Richard, P. Shrivastava, J. G. Siri, M. Stafford-Smith, J.-P. Toussaint and R. Webb (2016). "Defining and advancing a systems approach for sustainable cities." Current Opinion in Environmental Sustainability **23**: 69-78.
- Barr, S. and E. Woodley (2019). "Enabling communities for a changing climate: Re-configuring spaces of hazard governance." Geoforum **100**: 116-127.
- Becker, A. (2017). "Using boundary objects to stimulate transformational thinking: storm resilience for the Port of Providence, Rhode Island (USA)." Sustainability Science **12**(3): 477-501.

- Berke, P. R., M. L. Malecha, S. Yu, J. Lee and J. H. Masterson (2018). "Plan integration for resilience scorecard: evaluating networks of plans in six US coastal cities." Journal of Environmental Planning and Management **62**(5): 901-920.
- Berman, M., J. Baztan, G. Kofinas, J. P. Vanderlinden, O. Chouinard, J. M. Huctin, A. Kane, C. Maze, I. Nikulina and K. Thomson (2020). "Adaptation to climate change in coastal communities: findings from seven sites on four continents." Climatic Change **159**(1): 1-16.
- Binder, S. B., C. K. Baker and J. P. Barile (2015). "Rebuild or Relocate? Resilience and Postdisaster Decision-Making After Hurricane Sandy." American Journal of Community Psychology **56**(1-2): 180-196.
- Binder, S. B. and A. Greer (2016). "The Devil Is in the Details: Linking Home Buyout Policy, Practice, and Experience After Hurricane Sandy." Politics and Governance **4**(4): 97-106.
- Boruff, B. J., C. Emrich and S. L. Cutter (2005). "Erosion Hazard Vulnerability of US Coastal Counties." Journal of Coastal Research **21**5: 932-942.
- Bostick, T. P., T. H. Holzer and S. Sarkani (2017). "Enabling Stakeholder Involvement in Coastal Disaster Resilience Planning." Risk Analysis **37**(6): 1181-1200.
- Boyer-Villemaire, U., J. Benavente, J. A. G. Cooper and P. Bernatchez (2014). "Analysis of power distribution and participation in sustainable natural hazard risk governance: a call for active participation." Environmental Hazards **13**(1): 38-57.
- Bronen, R. (2014). "Choice and necessity: relocations in the Arctic and South Pacific." Forced Migration Review **45**: 17-21.
- Bronen, R. (2015). "Climate-induced community relocations: using integrated social-ecological assessments to foster adaptation and resilience." Ecology and Society **20**(3).

- Bronen, R. and F. S. Chapin (2013). "Adaptive governance and institutional strategies for climate-induced community relocations in Alaska." Proceedings of the National Academy of Sciences of the United States of America **110**(23): 9320-9325.
- Brubaker, M., J. Berner, R. Chavan and J. Warren (2011). "Climate change and health effects in Northwest Alaska." Global Health Action **4**.
- Brubaker, M. Y., J. N. Bell, J. E. Berner and J. A. Warren (2011). "Climate change health assessment: a novel approach for Alaska Native communities." International Journal of Circumpolar Health **70**(3): 266-273.
- Bukvic, A. and J. Harrauld (2019). "Rural versus urban perspective on coastal flooding: The insights from the U.S. Mid-Atlantic communities." Climate Risk Management **23**: 7-18.
- Bukvic, A., G. Rohat, A. Apotsos and A. de Sherbinin (2020). "A Systematic Review of Coastal Vulnerability Mapping." Sustainability **12**(7): 2822.
- Canada, P. S. (2008). Canada's National Disaster Mitigation Strategy. P. S. Canada: 1-11.
- Carlton, J. S. and S. K. Jacobson (2016). "Using Expert and Non-expert Models of Climate Change to Enhance Communication." Environmental Communication-a Journal of Nature and Culture **10**(1): 1-24.
- Cleary, W. J., K. T. Willson and C. W. Jackson (2006). "Shoreline restoration in high hazard zones: Southeastern north Carolina, USA." Journal of Coastal Research: 884-889.
- Close, S. L., F. Montalto, P. Orton, A. Antoine, D. Peters, H. Jones, A. Parris and A. Blumberg (2017). "Achieving sustainability goals for urban coasts in the US Northeast: research needs and challenges." Local Environment **22**(4): 508-522.
- Colten, C. E., J. R. Z. Simms, A. A. Grismore and S. A. Hemmerling (2018). "Social justice and mobility in coastal Louisiana, USA." Regional Environmental Change **18**(2): 371-383.

- Considine, C. and E. Steinhilber (2018). "Collaborative Strategies for Sea Level Rise Adaptation in Hampton Roads, Virginia." Journal of Green Building **13**(3): 195-214.
- Dannenbergh, A. L., H. Frumkin, J. J. Hess and K. L. Ebi (2019). "Managed retreat as a strategy for climate change adaptation in small communities: public health implications." Climatic Change **153**(1-2): 1-14.
- Doberstein, B., A. Tadgell and A. Rutledge (2020). "Managed retreat for climate change adaptation in coastal megacities: A comparison of policy and practice in Manila and Vancouver." Journal of Environmental Management **253**.
- Dorroh, E. E. I. (2020). "Relocation, Relocation, Relocation: Balancing Financial And Personal Needs in a Scenario Where Money is Scarce." LSU Journal of Energy Law and Resources **8**(2): 621-645.
- Esteban, M., J. Bricker, R. San Carlos Arce, H. Takagi, N. Y. Yun, W. Chaiyapa, A. Sjoegren and T. Shibayama (2018). "Tsunami awareness: a comparative assessment between Japan and the USA." Natural Hazards **93**(3): 1507-1528.
- Ewing, L. C. (2015). "Resilience from coastal protection." Philosophical Transactions of the Royal Society a-Mathematical Physical and Engineering Sciences **373**(2053).
- Finn, D., D. Chandrasekhar and Y. Xiao (2019). "A Region Recovers: Planning for Resilience after Superstorm Sandy." Journal of Planning Education and Research.
- Fischer, A. P. (2018). "Pathways of adaptation to external stressors in coastal natural-resource-dependent communities: Implications for climate change." World Development **108**: 235-248.
- Folke, C., T. Hahn, P. Olsson and J. Norberg (2005). "Adaptive governance of social-ecological systems." Annual Review of Environment and Resources **30**(1): 441-473.

- Fu, X. Y. (2020). "Measuring local sea-level rise adaptation and adaptive capacity: A national survey in the United States." Cities **102**.
- Fu, X. Y., M. Goma, Y. J. Deng and Z. R. Peng (2017). "Adaptation planning for sea level rise: a study of US coastal cities." Journal of Environmental Planning and Management **60**(2): 249-265.
- Fu, X. Y. and J. Song (2017). "Assessing the Economic Costs of Sea Level Rise and Benefits of Coastal Protection: A Spatiotemporal Approach." Sustainability **9**(8).
- Gerrity, B. F. and M. R. Phillips (2020). "Vulnerability and Resilience in San Mateo County: Identifying Social, Economic and Physical Discrepancies in Stakeholder Perception of Risk." Journal of Coastal Research **95**(sp1).
- Gerrity, B. F. and M. R. Phillips (2020). "Vulnerability and Resilience in San Mateo County: Identifying Social, Economic and Physical Discrepancies in Stakeholder Perception of Risk." Journal of Coastal Research: 803-807.
- Greer, A. and S. Brokopp Binder (2016). "A Historical Assessment of Home Buyout Policy: Are We Learning or Just Failing?" Housing Policy Debate **27**(3): 372-392.
- Griggs, G. B. (2015). "Lost Neighborhoods of the California Coast." Journal of Coastal Research **31**(1): 129-147.
- Güneralp, B., İ. Güneralp and Y. Liu (2015). "Changing global patterns of urban exposure to flood and drought hazards." Global Environmental Change **31**: 217-225.
- Hardy, R. D., R. A. Milligan and N. Heynen (2017). "Racial coastal formation: The environmental injustice of colorblind adaptation planning for sea-level rise." Geoforum **87**: 62-72.

- Hauer, M. E., J. M. Evans and D. R. Mishra (2016). "Millions projected to be at risk from sea-level rise in the continental United States." Nature Climate Change **6**(7): 691-695.
- Hay, A. H. (2014). "Briefing: Resilience: a developing planning tool." Infrastructure Asset Management **1**(4): 130-134.
- Hayes, A. L., E. C. Heery, E. Maroon, A. K. McLaskey and C. C. Stawitz (2018). "The role of scientific expertise in local adaptation to projected sea level rise." Environmental Science & Policy **87**: 55-63.
- Horney, J., M. C. Simon, K. Ricchetti-Masterson and P. Berke (2016). "Resident perception of disaster recovery planning priorities." International Journal of Disaster Resilience in the Built Environment **7**(4): 330-343.
- Joffe, H., G. Perez-Fuentes, H. W. W. Potts and T. Rossetto (2016). "How to increase earthquake and home fire preparedness: the fix-it intervention." Natural Hazards **84**(3): 1943-1965.
- Kauneckis, D. and R. Martin (2020). "Patterns of Adaptation Response by Coastal Communities to Climate Risks." Coastal Management **48**(4): 257-274.
- Kieval, M. (2020). "On Thin Ice: Exploring Solutions for Climate-Induced Displacement in the Face of Disappearing Permafrost." Arctic Yearbook 2020: 1-16.
- Kim, Y. and G. Newman (2019). "Climate Change Preparedness: Comparing Future Urban Growth and Flood Risk in Amsterdam and Houston." Sustainability **11**(4).
- Kirshen, P., M. Borrelli, J. Byrnes, R. Chen, L. Lockwood, C. Watson, K. Starbuck, J. Wiggin, A. Novelly, K. Uiterwyk, K. Thurson, B. McMann, C. Foster, H. Sprague, H. J. Roberts, K. Bosma, D. Jin and R. Herst (2020). "Integrated assessment of storm surge barrier systems under present and future climates and comparison to alternatives: a case study of Boston, USA." Climatic Change.

- Kondolf, G. M. and P. Lopez-Llompарт (2018). "National-local land-use conflicts in floodways of the Mississippi River system." AIMS Environmental Science **5**(1): 47-63.
- Kousky, C. (2014). "Managing shoreline retreat: a US perspective." Climatic Change **124**(1-2): 9-20.
- Lane, D., C. M. Clarke, D. L. Forbes and P. Watson (2013). "The Gathering Storm: managing adaptation to environmental change in coastal communities and small islands." Sustainability Science **8**(3): 469-489.
- Leichenko, R. M. and A. Thomas (2012). "Coastal Cities and Regions in a Changing Climate: Economic Impacts, Risks and Vulnerabilities." Geography Compass **6**(6): 327-339.
- Lindeman, K. C., L. E. Dame, C. B. Avenarius, B. P. Horton, J. P. Donnelly, D. R. Corbett, A. C. Kemp, P. Lane, M. E. Mann and W. R. Peltier (2015). "Science Needs for Sea-Level Adaptation Planning: Comparisons among Three US Atlantic Coastal Regions." Coastal Management **43**(5): 555-574.
- Lo, A. Y., B. Xu, F. K. S. Chan and R. Su (2015). "Social capital and community preparation for urban flooding in China." Applied Geography **64**: 1-11.
- Maldonado, A., T. W. Collins and S. E. Grineski (2019). "Hispanic Immigrants' Vulnerabilities to Flood and Hurricane Hazards in Two United States Metropolitan Areas." Geographical Review **106**(1): 109-135.
- Maldonado, J. K., C. Shearer, R. Bronen, K. Peterson and H. Lazrus (2013). "The impact of climate change on tribal communities in the US: displacement, relocation, and human rights." Climatic Change **120**(3): 601-614.

- Manrique, D. R., S. Corral and A. G. Pereira (2018). "Climate-related displacements of coastal communities in the Arctic: Engaging traditional knowledge in adaptation strategies and policies." Environmental Science & Policy **85**: 90-100.
- Manson, G. K., S. M. Solomon, D. L. Forbes, D. E. Atkinson and M. Craymer (2005). "Spatial variability of factors influencing coastal change in the western Canadian Arctic." Geo-Marine Letters **25**(2-3): 138-145.
- Marino, E. (2018). "Adaptation privilege and Voluntary Buyouts: Perspectives on ethnocentrism in sea level rise relocation and retreat policies in the US." Global Environmental Change-Human and Policy Dimensions **49**: 10-13.
- Masterson, J. H., W. G. Peacock, S. S. Van Zandt, H. Grover, L. F. Schwarz and J. T. Cooper (2014). An Assessment of Hazard Mitigation Plans. Planning for Community Resilience: A Handbook for Reducing Vulnerability to Disasters. Washington, DC, Island Press/Center for Resource Economics: 117-137.
- McGhee, D. J., S. B. Binder and E. A. Albright (2020). "First, Do No Harm: Evaluating the Vulnerability Reduction of Post-Disaster Home Buyout Programs." Natural Hazards Review **21**(1).
- McGinty, A. A. (2017). Home Buyouts: One Adaptation Approach to Rising Sea Levels. Master's, Tufts University.
- Miller, S. M. and F. A. Montalto (2019). "Stakeholder perceptions of the ecosystem services provided by Green Infrastructure in New York City." Ecosystem Services **37**.
- Minano, A., P. A. Johnson and J. Wandel (2018). "Visualizing flood risk, enabling participation and supporting climate change adaptation using the Geoweb: the case of coastal communities in Nova Scotia, Canada." Geojournal **83**(3): 413-425.

- Nakagawa, Y., Rajib Shaw (2004). "Social Capital: A Missing Link to Disaster Recovery." International Journal of Mass Emergencies and Disasters **22**(1): 5-34.
- Nelson, M. (2014). "Using Land Swaps to Concentrate Redevelopment and Expand Resettlement Options in Post-Hurricane Katrina New Orleans." Journal of the American Planning Association **80**(4): 426-437.
- Neumann, B., A. T. Vafeidis, J. Zimmermann and R. J. Nicholls (2015). "Future coastal population growth and exposure to sea-level rise and coastal flooding--a global assessment." PLoS One **10**(3): e0118571.
- Neumann, J. E., K. Emanuel, S. Ravela, L. Ludwig, P. Kirshen, K. Bosma and J. Martinich (2014). "Joint effects of storm surge and sea-level rise on US Coasts: new economic estimates of impacts, adaptation, and benefits of mitigation policy." Climatic Change **129**(1-2): 337-349.
- Norton, R. K., S. Buckman, G. A. Meadows and Z. Rable (2019). "Using Simple, Decision-Centered, Scenario-Based Planning to Improve Local Coastal Management." Journal of the American Planning Association **85**(4): 405-423.
- Peng, B. B. and J. Song (2018). "A Case Study of Preliminary Cost-Benefit Analysis of Building Levees to Mitigate the Joint Effects of Sea Level Rise and Storm Surge." Water **10**(2).
- Pinto, P. J., G. M. Kondolf and P. L. R. Wong (2018). "Adapting to sea level rise: Emerging governance issues in the San Francisco Bay Region." Environmental Science & Policy **90**: 28-37.
- Pinto, P. J. and M. Kondolf (2016). "Evolution of Two Urbanized Estuaries: Environmental Change, Legal Framework, and Implications for Sea-Level Rise Vulnerability." Water **8**(11).

- Portes, A. (2014). "Downsides of social capital." Proc Natl Acad Sci U S A **111**(52): 18407-18408.
- Rosenzweig, C., W. D. Solecki, R. Blake, M. Bowman, C. Faris, V. Gornitz, R. Horton, K. Jacob, A. LeBlanc, R. Leichenko, M. Linkin, D. Major, M. O'Grady, L. Patrick, E. Sussman, G. Yohe and R. Zimmerman (2011). "Developing coastal adaptation to climate change in the New York City infrastructure-shed: process, approach, tools, and strategies." Climatic Change **106**(1): 93-127.
- Shilling, F. M., J. Vandever, K. May, I. Gerhard and R. Bregoff (2016). "Adaptive Planning for Transportation Corridors Threatened by Sea Level Rise." Transportation Research Record(2599): 9-16.
- Siders, A. R. (2019). "Social justice implications of US managed retreat buyout programs." Climatic Change **152**(2): 239-257.
- Stevens, M. R. and J. Shoubridge (2014). "Municipal hazard mitigation planning: a comparison of plans in British Columbia and the United States." Journal of Environmental Planning and Management **58**(11): 1988-2014.
- Thorne, K. M., D. L. Elliott-Fisk, C. M. Freeman, T. V. D. Bui, K. W. Powelson, C. N. Janousek, K. J. Buffington and J. Y. Takekawa (2017). "Are coastal managers ready for climate change? A case study from estuaries along the Pacific coast of the United States." Ocean & Coastal Management **143**: 38-50.
- Vasseur, L., M. Thornbush and S. Plante (2017). "Climatic and Environmental Changes Affecting Communities in Atlantic Canada." Sustainability **9**(8).
- Wakefield, S. (2019). "Miami Beach forever? Urbanism in the back loop." Geoforum **107**: 34-44.

- Williams, S. and N. Ismail (2015). "Climate Change, Coastal Vulnerability and the Need for Adaptation Alternatives: Planning and Design Examples from Egypt and the USA." Journal of Marine Science and Engineering **3**(3): 591-606.
- Wilson, G. A., C. L. Kelly, H. Briassoulis, A. Ferrara, G. Quaranta, R. Salvia, V. Detsis, M. Curfs, A. Cerda, A. El-Aich, H. Liu, C. Kosmas, C. L. Alados, A. Imeson, R. Landgrebe-Trinkunaite, L. Salvati, S. Naumann, H. Danwen, T. Iosifides, T. Kizos, G. Mancino, A. Nolè, M. Jiang and P. Zhang (2017). "Social Memory and the Resilience of Communities Affected by Land Degradation." Land Degradation & Development **28**(2): 383-400.
- Wilson, M. T. (2018). "Catastrophes and their Classifications: Revising New York City's Hurricane Evacuation Maps after Irene and Sandy." Journal of Homeland Security and Emergency Management **15**(2).
- Wood, N., J. Jones, J. Schelling and M. Schmidtlein (2014). "Tsunami vertical-evacuation planning in the US Pacific Northwest as a geospatial, multi-criteria decision problem." International Journal of Disaster Risk Reduction **9**: 68-83.

APPENDIX A

A.1. List of search terms used

Database: Web of Science

Year range: 1900 to present

Last search accessed: July 31, 2020

Full search string (results = 1408)

TOPIC: (coast* OR shore*) AND (communit* OR urban* OR town OR settl* OR city OR cities
OR metro* OR megalo* OR built*) AND (resilien* OR vulnerab* OR hazard* OR mitigat* OR
adapt* OR expos* OR response OR recovery OR prevention OR prepared* OR emergency)
AND ("North America" OR "Northern America" OR "United States" OR USA OR US OR
Canada OR Canadian OR Arctic OR Bermuda OR Greenland) AND (SLR OR "sea level rise"
OR storm*OR flood* OR surge OR tsunami OR wind OR hurricane* OR subsid* OR erosion
OR intrusion OR tide* OR wave* OR inundat* OR disaster)

A.2. List of study journals

Table A.1. Synthesis of 67 articles from 47 journals.

Journal	Number of papers
Climatic Change	5
Natural Hazards	4
Coastal Management	3
Environmental Science & Policy	3
Journal of Coastal Research	3
Sustainability	3
Geoforum	2
Journal of Green Building	2
Regional Environmental Change	2
Sustainability Science	2
Water	2
American Journal of Community Psychology	2
Annals of the Association of American Geographers	1
Cities	1
Climate Risk Management	1
Ecology and Society	1
Environment	1
Environment and Planning B-Planning & Design	1
Geomorphology	1
Global Environmental Change-Human and Policy Dimensions	1

Global Health Action	1
International Journal of Circumpolar Health	1
International Journal of Climate Change Strategies and Management	1
International Journal of Disaster Resilience in the Built Environment	1
International Journal of Disaster Risk Reduction	1
International Journal of Tourism Cities	1
Journal of Environmental Planning and Management	1
Journal of Homeland Security and Emergency Management	1
Journal of Industrial Ecology	1
Journal of Marine Science and Engineering	1
Journal of Planning Education and Research	1
Journal of the American Planning Association	1
Landscape and Urban Planning	1
Local Environment	1
Mitigation and Adaptation Strategies for Global Change	1
Natural Hazards Review	1
Ocean & Coastal Management	1
Peerj	1
Philosophical Transactions of the Royal Society a-Mathematical	1
Physical and Engineering Sciences	
Proceedings of the National Academy of Sciences of the United States of America	1
Professional Geographer	1

Public Works Management & Policy	1
Risk Analysis	1
Socio-Economic Planning Sciences	1
Transportation Research Record	1
Urban Ecosystems	1
World Development	1
	1

A.3. List of comparative case study locations

Authors	Year	Title	Locations
Albert, S. Bronen, R. Tooler, N. Leon, J. Yee, D. Ash, J. Boseto, D. Grinham, A.	2017	Heading for the hills: climate-driven community relocations in the Solomon Islands and Alaska provide insight for a 1.5 degrees C future	(1) Shishmaref, Alaska (2) Solomon Islands
Berman, M. Baztan, J. Kofinas, G. Vanderlinden, J. P. Chouinard, O. Huctin, J. M. Kane, A. Maze, C. Nikulina, I. Thomson, K.	2020	Adaptation to climate change in coastal communities: findings from seven sites on four continents	(1) Uummannaq (Greenland) (2) Wainwright (Alaska, USA) (3) Cocagne-Grande-Digue (New Brunswick, Canada) (4) Tiksi (Sakha (Yakutia) Republic, Russian Federation) (5) Bay of Brest (Brittany, France) (6) Mbour (Senegal) (7) Vypin Island-Chellanam Peninsula (Kerala state, India)
Binder, S. B. Baker, C. K. Barile, J. P.	2015	Rebuild or Relocate? Resilience and Postdisaster Decision-Making After Hurricane Sandy	(1) Oakwood Beach, New York (2) Rockaway Park, New York
Bronen, R.	2015	Climate-induced community relocations: using integrated social-ecological assessments to foster adaptation and resilience	(1) Shishmaref (2) Newtok (3) Kivalina (4) Quinhagak
Bronen, R. Chapin, F. S.	2013	Adaptive governance and institutional strategies for climate-induced community relocations in Alaska	(1) Shishmaref (2) Newtok (3) Kivalina
Bukvic, A. Harrauld, J.	2019	Rural versus urban perspective on coastal flooding: The insights from the U.S. Mid-Atlantic communities	rural case studies (Eastern Shore): (1) Dorchester County (2) Talbot Counties urban case studies (Hampton Roads):

			(3) Chesapeake (4) Hampton (5) Newport News (6) Norfolk (7) Portsmouth
Burton, C. G.	2015	A Validation of Metrics for Community Resilience to Natural Hazards and Disasters Using the Recovery from Hurricane Katrina as a Case Study	(1) Hancock county, Mississippi (2) Harrison county, Mississippi (3) Jackson county, Mississippi
Chandra-Putra, H. Andrews, C. J.	2020	An integrated model of real estate market responses to coastal flooding	(1) Union Beach, New Jersey (2) Highlands, New Jersey
Cleary, W. J. Willson, K. T. Jackson, C. W.	2006	Shoreline restoration in high hazard zones: Southeastern north Carolina, USA	(1) North Topsail Beach, North Carolina (2) Surf City, North Carolina (3) Topsail Beach, North Carolina
Coles, J. Zhang, J. Zhuang, J.	2016	Partnership behavior in disaster relief operations: a case study comparison of the responses to the tornado in Joplin, Missouri and Hurricane Sandy along the Jersey Coast	(1) Joplin, Missouri (2) New York/New Jersey coast
Considine, C. Steinhilber, E.	2018	Collaborative Strategies for Sea Level Rise Adaptation in Hampton Roads, Virginia	Seventeen municipalities of Hampton Roads, Virginia
Cutter, S. L. Emrich, C. T. Mitchell, J. T. Boruff, B. J. Gall, M. Schmidtlein, M. C. Burton, C. G. Melton, G.	2006	The long road home: Race, class, and recovery from Hurricane Katrina	Gulf Coast counties affected by Katrina (Alabama, Louisiana, Mississippi)
Dannenbergh, 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	(1) Kivalina (2) Isle de Jean Charles (3) Taholah (4) Panama (5) Fiji

			(6) Papua New Guinea (7) Solomon Islands (8) Vanuatu
Esteban, M. Bricker, J. San Carlos Arce, R. Takagi, H. Yun, N. Y. Chaiyapa, W. Sjoegren, A. Shibayama, T.	2018	Tsunami awareness: a comparative assessment between Japan and the USA	(1) Miami Beach, Florida (2) Fort Meyers Beach, Florida (3) Clearwater Beach, Florida (4) Kamakura, Japan
Finn, D. Chandrasekhar, D. Xiao, Y.	2019	A Region Recovers: Planning for Resilience after Superstorm Sandy	(1) New York City, New York (2) Long Beach, New York (3) Hoboken, New York
Fischer, A. P.	2018	Pathways of adaptation to external stressors in coastal natural-resource-dependent communities: Implications for climate change	(1) Garibaldi, Oregon (2) Depoe Bay, Oregon (3) Newport, Oregon (4) Florence, Oregon (5) Port Orford, Oregon (6) Gold Beach, Oregon
Fu, X. Y.	2020	Measuring local sea-level rise adaptation and adaptive capacity: A national survey in the United States	(1) California (2) Florida (3) Maryland (4) New Jersey (5) Virginia
Fu, X. Y. Gomaa, M. Deng, Y. J. Peng, Z. R.	2017	Adaptation planning for sea level rise: a study of US coastal cities	(1) Baltimore, Maryland (2) Galveston, Texas (3) Los Angeles, California (4) Miami, Florida (5) New Orleans, Louisiana (6) New York City, New York (7) Providence, Rhode Island (8) San Francisco, California (9) Savannah, Georgia (10) Seattle, Washington (11) Virginia Beach, Virginia (12) Charleston, South Carolina (13) Philadelphia, Pennsylvania (14) San Diego, California (15) Tampa, Florida

Gerrity, B. F. Phillips, M. R.	2020	Vulnerability and Resilience in San Mateo County: Identifying Social, Economic and Physical Discrepancies in Stakeholder Perception of Risk	“bay side” and “coast side” of San Mateo County
Hayes, A. L. Heery, E. C. Maroon, E. McLaskey, A. K. Stawitz, C. C.	2018	The role of scientific expertise in local adaptation to projected sea level rise	92 coastal cities across US (Washington, Oregon, California, Texas, Hawai'i. Alaska, Louisiana, Alabama, Georgia, Florida, North Carolina, South Carolina, Virginia, Maryland, Delaware, New Jersey, Connecticut, Maine, New Hampshire)
Kauneckis, Derek Martin, Rachel	2020	Patterns of Adaptation Response by Coastal Communities to Climate Risks	coastal vs. non-coastal communities from the 50 US states, the District of Columbia, and the American Samoa, Guam, and Puerto Rico
Kerry, J. Pruneau, D. Blain, S. Langis, J. Barbier, P. Y. Mallet, M. A. Vichnevetski, E. Therrien, J. Deguire, P. Freiman, V. Lang, M. Laroche, A. M.	2012	Human competences that facilitate adaptation to climate change: a research in progress	(1) Bouctouche, Canada (2) Kent County, Canada
Kim, Y. Newman, G.	2019	Climate Change Preparedness: Comparing Future Urban Growth and Flood Risk in Amsterdam and Houston	(1) Houston, Texas (2) Amsterdam, the Netherlands
Lane, D. Clarke, C. M. Forbes, D. L. Watson, P.	2013	The Gathering Storm: managing adaptation to environmental change in coastal communities and small islands	(1) Charlottetown, Prince Edward Island, Canada (2) Georgetown, Guyana (3) Iqaluit, Nunavut, Canada (4) San Pedro, Ambergris Caye, Belize

			(5) Gibsons, British Columbia, Canada (6) Grande Riviere, Trinidad and Tobago (7) Isle Madame, Nova Scotia, Canada (8) Bequia, St. Vincent and the Grenadines
Lindeman, K. C. Dame, L. E. Avenarius, C. B. Horton, B. P. Donnelly, J. P. Corbett, D. R. Kemp, A. C. Lane, P. Mann, M. E. Peltier, W. R.	2015	Science Needs for Sea-Level Adaptation Planning: Comparisons among Three US Atlantic Coastal Regions	(1) Florida (2) North Carolina (3) Massachusetts
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	(1) Kivalina, Alaska (2) Newtok, Alaska (3) Isle de Jean Charles, Louisiana
Pinto, P. J. Kondolf, M.	2016	Evolution of Two Urbanized Estuaries: Environmental Change, Legal Framework, and Implications for Sea-Level Rise Vulnerability	(1) San Francisco Bay, California (2) Tagus Estuary, Lisbon, Portugal
Thorne, K. M. Elliott-Fisk, D. L. Freeman, C. M. Bui, T. V. D. Powelson, K. W. Janousek, C. N. Buffington, K. J. Takekawa, J. Y.	2017	Are coastal managers ready for climate change? A case study from estuaries along the Pacific coast of the United States	(1) Nisqually (2) Willapa Bay (3) Siletz Bay (4) Humboldt Bay (5) San Pablo Bay (6) Tijuana Slough
Vasseur, L. Thornbush, M. Plante, S.	2017	Climatic and Environmental Changes Affecting Communities in Atlantic Canada	(1) Rivière-au-Tonnerre, Canada (2) Bonaventure, Canada (3) Shippagan, Canada (4) Dundas, Canada

			(5) Stratford, Canada (6) Ste.-Flavie, Canada (7) Maria, Canada (8) Ste.-Marie-St.-Raphael, Canada (9) Cocagne-Grande Digue, Canada (10) Morell, Canada
Williams, S. J. Ismail, N.	2015	Climate Change, Coastal Vulnerability and the Need for Adaptation Alternatives: Planning and Design Examples from Egypt and the USA	(1) Lake Borgne, New Orleans, Louisiana (2) New York City, New York

A.4. Distribution of papers in the review

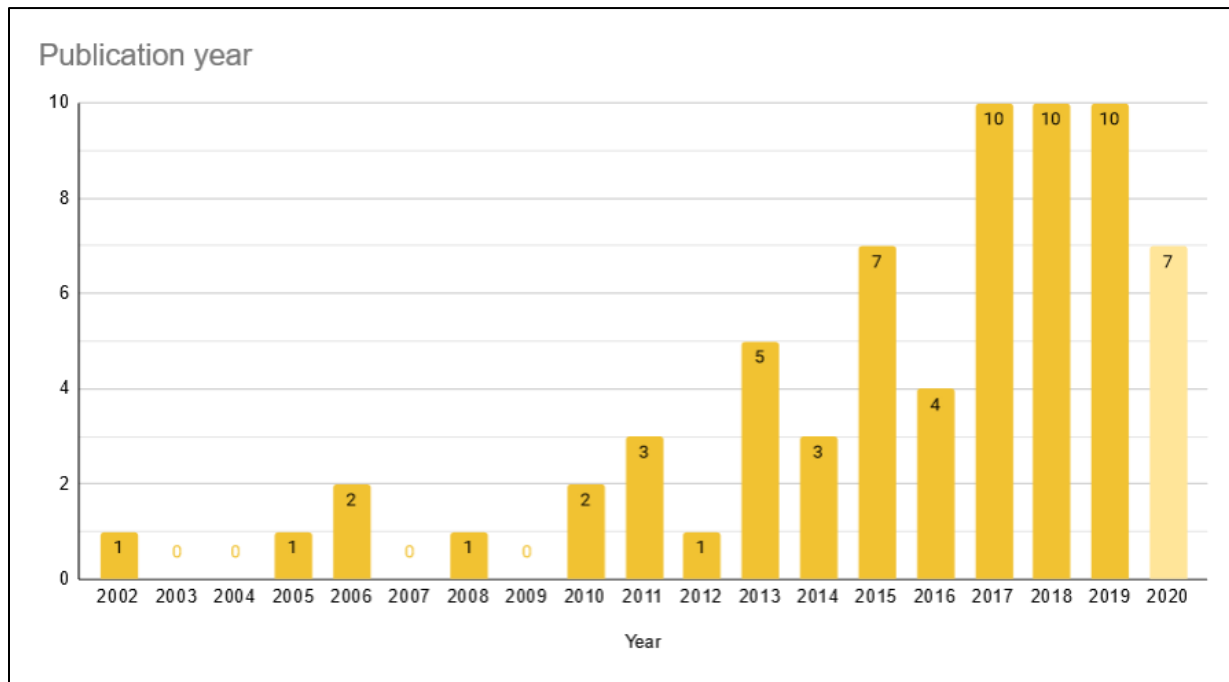


Figure A.1. Distribution of selected articles on hazard mitigation planning in North American coastal communities with input from stakeholders, either in the form of participation in planning or as sharing perceptions of hazards or hazard mitigation planning. Publications in 2020 were included until July 31.

A.5. Papers included in the review

Albert, S., R. Bronen, N. Tooler, J. Leon, D. Yee, J. Ash, D. Boseto and A. Grinham (2018).

"Heading for the hills: climate-driven community relocations in the Solomon Islands and Alaska provide insight for a 1.5 degrees C future." Regional Environmental Change **18**(8): 2261-2272.

Becker, A. (2017). "Using boundary objects to stimulate transformational thinking: storm resilience for the Port of Providence, Rhode Island (USA)." Sustainability Science **12**(3): 477-501.

Berman, M., J. Baztan, G. Kofinas, J. P. Vanderlinden, O. Chouinard, J. M. Huctin, A. Kane, C. Maze, I. Nikulina and K. Thomson (2020). "Adaptation to climate change in coastal communities: findings from seven sites on four continents." Climatic Change **159**(1): 1-16.

Bernard, E. N. (2005). "The US National Tsunami Hazard Mitigation Program: A successful State-Federal partnership." Natural Hazards **35**(1): 5-24.

Binder, S. B., C. K. Baker and J. P. Barile (2015). "Rebuild or Relocate? Resilience and Postdisaster Decision-Making After Hurricane Sandy." American Journal of Community Psychology **56**(1-2): 180-196.

Bostick, T. P., T. H. Holzer and S. Sarkani (2017). "Enabling Stakeholder Involvement in Coastal Disaster Resilience Planning." Risk Analysis **37**(6): 1181-1200.

Bronen, R. (2015). "Climate-induced community relocations: using integrated social-ecological assessments to foster adaptation and resilience." Ecology and Society **20**(3).

Bronen, R. and F. S. Chapin (2013). "Adaptive governance and institutional strategies for climate-induced community relocations in Alaska." Proceedings of the National Academy of Sciences of the United States of America **110**(23): 9320-9325.

- Brubaker, M., J. Berner, R. Chavan and J. Warren (2011). "Climate change and health effects in Northwest Alaska." Global Health Action **4**.
- Brubaker, M. Y., J. N. Bell, J. E. Berner and J. A. Warren (2011). "Climate change health assessment: a novel approach for Alaska Native communities." International Journal of Circumpolar Health **70**(3): 266-273.
- Bukvic, A. and J. Harrauld (2019). "Rural versus urban perspective on coastal flooding: The insights from the U.S. Mid-Atlantic communities." Climate Risk Management **23**: 7-18.
- Burger, J., K. M. O'Neill, S. N. Handel, B. Hensold and G. Ford (2017). "The shore is wider than the beach: Ecological planning solutions to sea level rise for the Jersey Shore, USA." Landscape and Urban Planning **157**: 512-522.
- Burger, J. and N. Tsipoura (2019). "Resident status influences perceptions about beach resource valuation and restoration." Urban Ecosystems **22**(4): 785-793.
- Burton, C. G. (2015). "A Validation of Metrics for Community Resilience to Natural Hazards and Disasters Using the Recovery from Hurricane Katrina as a Case Study." Annals of the Association of American Geographers **105**(1): 67-86.
- Camare, H. M. and D. E. Lane (2015). "Adaptation analysis for environmental change in coastal communities." Socio-Economic Planning Sciences **51**: 34-45.
- Carpenter, A. T. (2020). "Public priorities on locally-driven sea level rise planning on the East Coast of the United States." PeerJ **8**.
- Chandra-Putra, H. and C. J. Andrews (2020). "An integrated model of real estate market responses to coastal flooding." Journal of Industrial Ecology **24**(2): 424-435.

- Chapin, T. S., R. E. Deyle and E. J. Baker (2008). "A parcel-based GIS method for evaluating conformance of local land-use planning with a state mandate to reduce exposure to hurricane flooding." Environment and Planning B-Planning & Design **35**(2): 261-279.
- Cleary, W. J., K. T. Willson and C. W. Jackson (2006). "Shoreline restoration in high hazard zones: Southeastern north Carolina, USA." Journal of Coastal Research: 884-889.
- Close, S. L., F. Montalto, P. Orton, A. Antoine, D. Peters, H. Jones, A. Parris and A. Blumberg (2017). "Achieving sustainability goals for urban coasts in the US Northeast: research needs and challenges." Local Environment **22**(4): 508-522.
- Coles, J., J. Zhang and J. Zhuang (2016). "Partnership behavior in disaster relief operations: a case study comparison of the responses to the tornado in Joplin, Missouri and Hurricane Sandy along the Jersey Coast." Natural Hazards **84**(1): 625-647.
- Colten, C. E., J. R. Z. Simms, A. A. Grismore and S. A. Hemmerling (2018). "Social justice and mobility in coastal Louisiana, USA." Regional Environmental Change **18**(2): 371-383.
- Considine, C. and E. Steinhilber (2018). "Collaborative Strategies for Sea Level Rise Adaptation in Hampton Roads, Virginia." Journal of Green Building **13**(3): 195-214.
- Conyers, Z. A., R. Grant and S. Sen Roy (2019). "Sea Level Rise in Miami Beach: Vulnerability and Real Estate Exposure." Professional Geographer **71**(2): 278-291.
- Cutter, S. L., C. T. Emrich, J. T. Mitchell, B. J. Boruff, M. Gall, M. C. Schmidtlein, C. G. Burton and G. Melton (2006). "The long road home: Race, class, and recovery from Hurricane Katrina." Environment **48**(2): 8-20.
- Dannenberg, A. L., H. Frumkin, J. J. Hess and K. L. Ebi (2019). "Managed retreat as a strategy for climate change adaptation in small communities: public health implications." Climatic Change **153**(1-2): 1-14.

- Davlasheridze, M., K. O. Atoba, S. Brody, W. Highfield, W. Merrell, B. Ebersole, A. Purdue and R. W. Gilmer (2019). "Economic impacts of storm surge and the cost-benefit analysis of a coastal spine as the surge mitigation strategy in Houston-Galveston area in the USA." Mitigation and Adaptation Strategies for Global Change **24**(3): 329-354.
- Donatuto, J., E. E. Grossman, J. Konovsky, S. Grossman and L. W. Campbell (2014). "Indigenous Community Health and Climate Change: Integrating Biophysical and Social Science Indicators." Coastal Management **42**(4): 355-373.
- Esteban, M., J. Bricker, R. San Carlos Arce, H. Takagi, N. Y. Yun, W. Chaiyapa, A. Sjoegren and T. Shibayama (2018). "Tsunami awareness: a comparative assessment between Japan and the USA." Natural Hazards **93**(3): 1507-1528.
- Ewing, L. C. (2015). "Resilience from coastal protection." Philosophical Transactions of the Royal Society a-Mathematical Physical and Engineering Sciences **373**(2053).
- Finn, D., D. Chandrasekhar and Y. Xiao (2019). "A Region Recovers: Planning for Resilience after Superstorm Sandy." Journal of Planning Education and Research.
- Fischer, A. P. (2018). "Pathways of adaptation to external stressors in coastal natural-resource-dependent communities: Implications for climate change." World Development **108**: 235-248.
- Froede, C. R. (2010). "Constructed Sand Dunes on the Developed Barrier-Spit Portion of Dauphin Island, Alabama (USA)." Journal of Coastal Research **26**(4): 699-703.
- Fu, X. Y. (2020). "Measuring local sea-level rise adaptation and adaptive capacity: A national survey in the United States." Cities **102**.

- Fu, X. Y., M. Goma, Y. J. Deng and Z. R. Peng (2017). "Adaptation planning for sea level rise: a study of US coastal cities." Journal of Environmental Planning and Management **60**(2): 249-265.
- Fu, X. Y. and J. Song (2017). "Assessing the Economic Costs of Sea Level Rise and Benefits of Coastal Protection: A Spatiotemporal Approach." Sustainability **9**(8).
- Gerrity, B. F. and M. R. Phillips (2020). "Vulnerability and Resilience in San Mateo County: Identifying Social, Economic and Physical Discrepancies in Stakeholder Perception of Risk." Journal of Coastal Research: 803-807.
- Hardy, R. D., R. A. Milligan and N. Heynen (2017). "Racial coastal formation: The environmental injustice of colorblind adaptation planning for sea-level rise." Geoforum **87**: 62-72.
- Hayes, A. L., E. C. Heery, E. Maroon, A. K. McLaskey and C. C. Stawitz (2018). "The role of scientific expertise in local adaptation to projected sea level rise." Environmental Science & Policy **87**: 55-63.
- Horney, J., M. C. Simon, K. Ricchetti-Masterson and P. Berke (2016). "Resident perception of disaster recovery planning priorities." International Journal of Disaster Resilience in the Built Environment **7**(4): 330-343.
- Kauneckis, D. and R. Martin (2020). "Patterns of Adaptation Response by Coastal Communities to Climate Risks." Coastal Management **48**(4): 257-274.
- Kerry, J., D. Pruneau, S. Blain, J. Langis, P. Y. Barbier, M. A. Mallet, E. Vichnevetski, J. Therrien, P. Deguire, V. Freiman, M. Lang and A. M. Laroche (2012). "Human competences that facilitate adaptation to climate change: a research in progress." International Journal of Climate Change Strategies and Management **4**(3): 246-259.

- Kim, Y. and G. Newman (2019). "Climate Change Preparedness: Comparing Future Urban Growth and Flood Risk in Amsterdam and Houston." Sustainability **11**(4).
- Kirshen, P., M. Borrelli, J. Byrnes, R. Chen, L. Lockwood, C. Watson, K. Starbuck, J. Wiggin, A. Novelly, K. Uiterwyk, K. Thurson, B. McMann, C. Foster, H. Sprague, H. J. Roberts, K. Bosma, D. Jin and R. Herst (2020). "Integrated assessment of storm surge barrier systems under present and future climates and comparison to alternatives: a case study of Boston, USA." Climatic Change.
- Lane, D., C. M. Clarke, D. L. Forbes and P. Watson (2013). "The Gathering Storm: managing adaptation to environmental change in coastal communities and small islands." Sustainability Science **8**(3): 469-489.
- Lindell, M. K. and C. S. Prater (2010). "Tsunami Preparedness on the Oregon and Washington Coast: Recommendations for Research." Natural Hazards Review **11**(2): 69-81.
- Lindeman, K. C., L. E. Dame, C. B. Avenarius, B. P. Horton, J. P. Donnelly, D. R. Corbett, A. C. Kemp, P. Lane, M. E. Mann and W. R. Peltier (2015). "Science Needs for Sea-Level Adaptation Planning: Comparisons among Three US Atlantic Coastal Regions." Coastal Management **43**(5): 555-574.
- Maldonado, J. K., C. Shearer, R. Bronen, K. Peterson and H. Lazrus (2013). "The impact of climate change on tribal communities in the US: displacement, relocation, and human rights." Climatic Change **120**(3): 601-614.
- Manrique, D. R., S. Corral and A. G. Pereira (2018). "Climate-related displacements of coastal communities in the Arctic: Engaging traditional knowledge in adaptation strategies and policies." Environmental Science & Policy **85**: 90-100.

- Morris, J. C., M. W. McNamara and A. Belcher (2019). "Building Resilience Through Collaboration Between Grassroots Citizen Groups and Governments: Two Case Studies." Public Works Management & Policy **24**(1): 50-62.
- Nelson, M. (2014). "Using Land Swaps to Concentrate Redevelopment and Expand Resettlement Options in Post-Hurricane Katrina New Orleans." Journal of the American Planning Association **80**(4): 426-437.
- Nordstrom, K. F., N. L. Jackson, M. S. Bruno and H. A. de Butts (2002). "Municipal initiatives for managing dunes in coastal residential areas: a case study of Avalon, New Jersey, USA." Geomorphology **47**(2-4): 137-152.
- Peng, B. B. and J. Song (2018). "A Case Study of Preliminary Cost-Benefit Analysis of Building Levees to Mitigate the Joint Effects of Sea Level Rise and Storm Surge." Water **10**(2).
- Pinto, P. J., G. M. Kondolf and P. L. R. Wong (2018). "Adapting to sea level rise: Emerging governance issues in the San Francisco Bay Region." Environmental Science & Policy **90**: 28-37.
- Pinto, P. J. and M. Kondolf (2016). "Evolution of Two Urbanized Estuaries: Environmental Change, Legal Framework, and Implications for Sea-Level Rise Vulnerability." Water **8**(11).
- Rosenzweig, C., W. D. Solecki, R. Blake, M. Bowman, C. Faris, V. Gornitz, R. Horton, K. Jacob, A. LeBlanc, R. Leichenko, M. Linkin, D. Major, M. O'Grady, L. Patrick, E. Sussman, G. Yohe and R. Zimmerman (2011). "Developing coastal adaptation to climate change in the New York City infrastructure-shed: process, approach, tools, and strategies." Climatic Change **106**(1): 93-127.

Shilling, F. M., J. Vandever, K. May, I. Gerhard and R. Bregoff (2016). "Adaptive Planning for Transportation Corridors Threatened by Sea Level Rise." Transportation Research Record(2599): 9-16.

Thorne, K. M., D. L. Elliott-Fisk, C. M. Freeman, T. V. D. Bui, K. W. Powelson, C. N.

Janousek, K. J. Buffington and J. Y. Takekawa (2017). "Are coastal managers ready for climate change? A case study from estuaries along the Pacific coast of the United States." Ocean & Coastal Management **143**: 38-50.

Treuer, G., K. Broad and R. Meyer (2018). "Using simulations to forecast homeowner response to sea level rise in South Florida: Will they stay or will they go?" Global Environmental Change-Human and Policy Dimensions **48**: 108-118.

Usher, L. E., J.-E. Yusuf and M. Covi (2019). "Assessing tourism business resilience in Virginia Beach." International Journal of Tourism Cities **6**(2): 397-414.

Van Meter, J. and T. W. Schmidlin (2013). "Hurricane preparedness and planning in coastal public school districts in the United States." Natural Hazards **66**(2): 1029-1036.

Vasseur, L., M. Thornbush and S. Plante (2017). "Climatic and Environmental Changes Affecting Communities in Atlantic Canada." Sustainability **9**(8).

Wakefield, S. (2019). "Miami Beach forever? Urbanism in the back loop." Geoforum **107**: 34-44.

Williams, S. J. and N. Ismail (2015). "Climate Change, Coastal Vulnerability and the Need for Adaptation Alternatives: Planning and Design Examples from Egypt and the USA." Journal of Marine Science and Engineering **3**(3): 591-606.

- Wilson, M. T. (2018). "Catastrophes and their Classifications: Revising New York City's Hurricane Evacuation Maps after Irene and Sandy." Journal of Homeland Security and Emergency Management **15**(2).
- Wood, N., J. Jones, J. Schelling and M. Schmidtlein (2014). "Tsunami vertical-evacuation planning in the US Pacific Northwest as a geospatial, multi-criteria decision problem." International Journal of Disaster Risk Reduction **9**: 68-83.
- Zurek, S. R. (2019). "Equitable Adaptation Planning in Historic Coastal Cities: Observations from an Architectural Practice." Journal of Green Building **14**(1): 201-216.