Cumulative Impact of Repeated Wildfire Displacement Events on Migration in the Western United States

A Thesis Presented

by

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Submitted to the Graduate School of the
University of Massachusetts Amherst in partial fulfillment
of the requirements for the degree of

MASTER OF REGIONAL PLANNING

May 2023

Department of Landscape Architecture and Regional Planning

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ACKNOWLEDGMENTS

I would like to thank my thesis committee for their willingness to support my ambitious research pursuits. Thank you for sharing your knowledge, providing excellent guidance, and inviting me into learning opportunities that I never imagined at the outset of my time at UMass. I'd also like to thank my partner Jamille Kort for her constant support throughout my graduate school journey.

ABSTRACT

CUMULATIVE IMPACT OF WILDFIRE DISPLACEMENT EVENTS

ON MIGRATION IN THE WESTERN US

MAY 2023

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Climate migration has been identified as an urgent issue that will likely add greater complexity to existing climate change planning efforts (Black, 2011; Ahsan, 2011). Existing climate migration literature has primarily focused on international migration and the Global South, offering limited applicability to internal conditions in developed countries due to the issue’s high context dependency (Hoffman, 2020). Local and municipal planners have a responsibility to pursue evidence-based climate adaptation strategies (Mitchell, 2020). Yet, planners lack reliable data to forecast potential changes to regional migration based on repeated exposure to climate stressors. To date, research has been primarily qualitative in nature, leaving a need for quantitative, spatial studies to detect larger patterns in comparison to survey and interview-based findings (Piguet et al., 2018). Within developed countries, research that integrates environmental factors into typical migration estimation methods used by community development and economic planners is needed to determine the extent that rapid environmental change may alter existing migration trends. In beginning to address this gap, this study tests the relationship between wildfire displacement events (i.e. evacuation events) and household out-migration rates amid a host of competing socioeconomic factors for all western US counties during years 2016-2019. Wildfire displacement data from the Internal Displacement Monitoring Centre (IDMC) is combined with out-migration estimates from the IRS SOI program in a times series, then joined to cross-sectional census data on county demographics to form a panel dataset for investigation. Modeling results show an expected 1.5% decrease in household out-migration rates for county-years experiencing repeated wildfire displacement events in comparison to non-treatment county-years. These results suggest a potential lowering of mobility capacity or desire within impacted communities for areas experiencing repeated wildfire. Whether this is linked to impacts on economic resources, i.e., exaggeration of underlying vulnerabilities, or suppressed desire to move, is unclear. Direct implications for planners depend on greater understanding of causality. The study suggests that climate-related wildfire migration in the US warrants continued research, especially with focus on equity implications of unequal access to migration as a method of climate adaptation.

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LIST OF ABBREVIATIONS

ACS – American Community Survey

GIS – geographic information systems

IDMC – Internal Displacement Monitoring Centre

IPCC - Intergovernmental Panel on Climate Change

IRS – Internal Revenue Service

SOI – IRS Statistics of Income program

WUI – Wildland Urban Interface

GLOSSARY

This thesis uses the term “climate-related hazards” or “climate hazards” as defined by the Intergovernmental Panel on Climate Change (IPCC) and Internal Displacement Monitoring Centre (IDMC) instead of the colloquial or common term “natural disasters.” Such wording provides space for distinction between the climatically influenced physical impacts on environments and livelihoods versus social context which may affect or moderate the experience of disaster.

Climate Hazard – Climate-related physical events or trends including sudden onset hazards such as floods, storms, extreme temperature events, and wildfires; and slow onset hazards such as drought, salinization, ocean acidification, seasonal changes, glacial retreat, and sea-level rise (IPCC, 2014b; IDMC, 2017; Stapleton et al., 2017)

Disaster – Severe alteration in the normal functioning of a community or a society due to hazardous physical events interacting with vulnerable social conditions, leading to widespread adverse human, material, economic, or environmental effects (IPCC, 2014b; Stapleton et al., 2017) or, when stated, FEMA-designated disaster-level events.

Climate Hazard Vulnerability – A combination of exposure of underlying socio-economic systems to a natural disaster such as wildfire and that system or individual’s adaptive capacity to “absorb, recover, and modify exposure to the hazard” (Davies et al., 2018)

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CHAPTER 1. INTRODUCTION

The era of globalized climate change suggests the need to re-evaluate how more rapid and widespread climatic shifts may influence future human migration patterns. As the landscapes and local economies that rely upon them change, communities may experience more scarcity, competition, and conflict around resources in ways that adversely affect individuals' well-being and livelihoods. In response, people around the world may relocate due to environmental stressors such as drought, sea level rise, or natural disaster. Shifts in human migration patterns due to unprecedented environmental change may lead to compounding impacts such as economic disruption, exponential urbanization, and aggravation of existing resource inequalities (Black et al., 2011; Ahsan, 2011). These matters may complicate and add further uncertainty to ongoing climate change planning efforts. From a planning perspective, there is a need to continue developing an understanding of emergent climate migration trends to inform future planning efforts.

While climate migration studies have progressed substantially since the initial conceptualization of the *environmental refugee* in the 1980's, a "heterogeneity of research findings" (Hoffmann et al., 2020; Piguet, 2011; De Haas, 2021) and increasing complexity of migration theory suggest the need for further study on processes and outcomes (Piguet et al., 2018; Hunter et al., 2015). The inability to achieve consensus on how environmental factors affect migration is largely due to the context dependency of the issue (Hoffmann et al., 2020). Environmental stressors vary themselves and yet are only one of many interrelated variables influencing migration decisions. As such, environmental stressors are best understood when situated within broader connections to local economic and socio-political conditions which in turn vary on a regional basis (Black et al., 2011).

Recent literature reviews have found a polarity in climate migration research between the Global North and South that highlights the need for more investigation into emergent patterns within developed countries (Kaczan and Orgill-Meyer, 2020). Findings suggest that climate migration operates similar to traditional economics migration theories on distance constraints with individuals and groups being more likely to move shorter distances often within their home country (ibid., Findlay, 2011; IOM Environmental Migration Portal, 2021) despite Western countries' historic focus on international immigration studies (Piguet et al., 2018). Researchers are calling for developed countries such as the US to reflect on how emerging internal climate migration trends may influence existing domestic inequities and immigration policy (Yayboke, 2020; IOM Migration Portal, 2021).

Within the US, climate migration studies have largely been conducted on hurricane impacts, following a global research pattern trending toward natural disasters, justified by the predominance of their impact on displacement. In 2020, approximately 98% of new displacement was instigated by weather-related disasters and the US ranked in the top five countries for disaster-based displacement (IOM Migration Portal, 2021; IDMC Global Report of Internal Displacement, 2021).

The research bias towards natural disasters is also explained by the lack of comprehensive data on other types of climate hazards especially slow onset climate stressors (Hunter, 2015; Piguet et al., 2018; Hoffmann et al., 2020). Accordingly, climate migration analyses have typically been focused on disaster-based case studies, overwhelmingly qualitative in nature, or used quantitative approaches on climatic conditions such as historic changes in precipitation or temperature (Hoffmann et al., 2020; IOM Migration Portal, 2021). There remains a need for empirical, spatial research applying quantitative methods to study how environmental, regional, and demographic characteristics relate to environmental mobility, especially in the context of developed countries (Piguet et al., 2018; IOM Migration Portal, 2021).

This study aims to address the above research gaps through an investigation of the relationship between repeated natural hazard displacement, domestic migration patterns, and area demographics within the western US. Studying repeated hazard-related displacement is proposed for its relationship to the concept of cumulative impact, representing a variable found somewhere in the middle of the slow to sudden onset climate stressor spectrum. To achieve this, a relatively new data source, the Internal Displacement Monitoring Centre, is used to acquire data on the incidence of wildfire displacement events that can be compared to total migration estimates and area characteristics at a county-level scale.

This thesis uses a distinction between displacement, representing the forced movement of people that may be on a temporary basis (IDMC, 2021), versus migration referring to permanent relocation. Oftentimes these two categories of mobility are combined into a more expansive definition (such as used for “environmental migrants” by the UN International Organization for Migration (UN IOM, 2014). This paper uses the differentiation to study the relationship between incidence of temporary displacement and more permanent climate migration, based on the number of repeated wildfire displacement events when viewed amid the context of competing socioeconomic factors.

Wildfire has been chosen as the primarily natural hazard type for investigation based on its prevalence in the US landscape and therefore its contribution to displacement as determined by preliminary study of the IDMC data. Despite being the most frequent category of natural disaster in the US, wildfire has been historically underrepresented in climate migration study (Winkler and Rouleau, 2020; McConnell et al., 2021).

1.1 Research Objectives and Questions

Primary Objective: Measure the potential cumulative impact of repeated sudden-onset climate wildfire hazards on migration patterns in the western United States.

RQ1: Do counties experiencing repeated wildfire displacement events experience more out-migration than counties not experiencing wildfire events?

Exploratory Objective: Measure socioeconomic characteristics of environmental mobility trends within the focus region.

RQ2: If so, what are the socioeconomic trends of wildfire-prone counties? What might we learn about populations at risk?

CHAPTER 2. LITERATURE REVIEW

Detecting or projecting how rapid environmental shifts may affect migration patterns requires an understanding of how people are vulnerable to climate change and the ways they may adapt to it (Piguet, 2011). Social responses to climate change have been defined within the two primary categories of mitigation and adaptation. Climate mitigation refers to actions taken to reduce the sources of climate change, such as lowering greenhouse gas emissions (IPCC, 2001a; Klein et al., 2007). Climate adaptation describes actions that lessen the harm and impacts brought on by climate change, whether by building above projected ocean elevations, improving disaster communication networks, or removing oneself from areas of environmental risk (Ibid). This study is based upon the understanding of migration as a form of adaptation to local changes brought on or aggravated by climate change (Black et al., 2011). Climate migration, defined by the act of voluntarily or involuntarily moving away from environmentally stressed locations, is considered one strategy amid many options or capacities that are influenced by a host of social, economic, and political factors.

Environmental mobility, coming from the inter-disciplinary 'mobility turn' of the social sciences, is the contemporary language used to encompass the plurality of observed outcomes related to migration in the age of rapid climatic change (Sheller and Urry, 2006; Wiegel et al., 2019). Within the mobility paradigm diverse human responses to environmental threats are understood along a continuum of mobility, i.e., the movement of people, and immobility, i.e., the lack of movement or inability to move, where interacting personal and structural factors can moderate or facilitate the relationship between these outcomes (Carling and Schewel, 2018; Wiegel et al., 2019; Schewel, 2019). Simply put, in the face of environmental threat or disaster, some people move while others do not. The environmental mobility framework, which composes the theoretical grounding of this study and is explored further within the following literature review, provides space to consider how issues like social vulnerability, adaptive capacity, and cultural landscape values affect diverse mobility outcomes. Studying climate migration through a mobility framework is beneficial to planners in that it provides opportunity to consider how existing climate change planning efforts and social programs can support positive outcomes in the face of rising natural hazards or identify areas in need of new intervention.

The review below begins by defining terminology used to describe the relationship between various climate change impacts and the risks they impose upon human displacement and migration. Afterwards, the historic evolution of climate migration research and relevant theory is discussed, building to the contemporary immobility/mobility concept, as a means of providing context for interpreting emerging US research. While literature on climate migration and, more broadly, environmental mobility has greatly expanded over the past 50 years, there remains relatively little research in the context of developed countries such as the US. The lessons gleaned from past international research and the academic criticism that has informed more critical approaches today are useful in guiding this study's research design and conceptual framework. The section then ends with a review of recent investigations of wildfire-related migration in the US and how findings suggest a need for continued research on the potential cumulative effects of repeated exposure to wildfire in the west.

2.1 Mobility Along the Climate Stressor Spectrum

Climate change poses widespread environmental risks that may occur at various spatial extents and temporal frequencies. Impacts already being felt across the world include worsening drought, rising temperatures, higher rainfall affecting flooding, sea level rise, and more intense and frequent severe storms (Blunden and Arndt, 2017;

Stapleton et al., 2017). To capture this variability of type and scale, climate change hazards associated with mobility are often categorized as sudden or slow-onset stressors (UNFCC, 2012). Within this classification, sudden (or rapid) onset climate hazards are considered single events that occur over a defined period of hours or days. Impacts from sudden-onset stressors are often immediate, destructive, yet fleeting (Ibid). Sudden onset climate hazards typically include climate-aggravated natural disasters such as hurricanes, major storms, extreme temperature events (heat wave and/or cold snaps), and floods (Ibid). This climate hazard type contributes to growing human displacement, defined as the forced dislocation of people from their homes or places of habitual residence on a temporary basis (IDMC, 2017). Disaster evacuees are a primary example of populations experiencing displacement.

There is a distinction to make here between the temporary or unresolved nature of displacement versus migration, which describes permanent relocation to a new area. While both displacement and migration can result from a choice made under duress, displacement suggests the potential for return such as when people return home after the ending of a mandatory evacuation order, as compared to migration, which suggests a period of extended relocation. However, research studying long-term cycles of 'return migration' within regional migration systems complicates this distinction (Fussell and Elliott, 2009; Curtis et al., 2015). It is important to keep in mind that migration, like climate hazards themselves, can operate at numerous spatial and temporal scales that makes the study of human mobility in relation to environmental stressors complex. For the purposes of this thesis, which examines migration in relationship to estimates of temporary displacement in response to climate-aggravated wildfire hazards, the differentiation between displacement and migration remains necessary.

As opposed to sudden-onset stressors, slow-onset climate hazards describe the effects of more gradual or incremental climate change over the course of years (UNFCC, 2012). Examples of slow-onset climate hazards include drought, desertification, ocean acidification, glacial retreat, sea-level rise, season creep, and phenological shifts (Stapleton et al., 2017). Slow stressors tend to last longer, bring more permanent changes, and contribute to cascading regional impacts. The threat of sea-level rise is a primary example of this, bringing the potential to physically reconfigure the shoreline via changes in average ocean tidal elevations and thus alter development in many prominent coastal cities across the world (Ibid). Slow-onset climate hazards can contribute to gradual environmental degradation affecting the scarcity of resources and land availability, thus in turn disturbing and endangering livelihoods. In this way, the extent of impacts from slow-onset stressors are deeply linked to the sustainability and/or resiliency of development, agriculture, and land management practices employed in different locales (IDMC, 2018).

There are also inherent relationships between sudden and slow onset stressors that complicate a clean division of events and instead suggest the utility of conceptualizing climate hazards along a spectrum or continuum. Drought for example, which is considered an extreme weather event or a relatively short climatic event, is projected to become more persistent under the new conditions of anthropogenic climate change making it more difficult to classify (IPCC 2007; Littell, 2016; Stapleton, 2017). Additionally, researchers recognize the impacts of combined or subsequent slow-onset and sudden-onset climate hazard interactions, such as when sea-level rise degrades protective coastal ecosystems, such as mangroves, leaving coastal communities more exposed to storm surge impacts that could result in displacement or migration (IDMC, 2018). Typically, slow-onset climate hazards make populations more vulnerable to sudden-onset events (Ibid). As such, recent publications recognize the grey area between sudden and slow-onset climate stressors. In some cases, the definition of slow-onset hazards might include incremental climatic change as a result of increasing frequency and intensity of recurring hazard events (UNFCC, 2012). Other times new terms are proposed, such as in Stapleton et al., who use the two intermediary categories of “slow or repeated sudden-onset” and “sudden-medium onset” hazards that are more likely linked to migration on a long-term basis (Stapleton et al., 2017).

The relationship between each hazard type and mobility outcomes is dependent on how the scale and frequency of impacts alter the vulnerability and adaptive capacity of affected populations (Ibid; Schewel, 2019). Some findings suggests that the more permanent environmental changes associated with slow-onset hazards are likewise linked to more permanent migration, while other research indicates that the longer change horizons of slow-onset hazards provide more time for resident communities to adapt in place, thereby moderating migration (Kaczan and Orgill-Meyer, 2019; Stapleton et al., 2017). Sudden-medium onset stressors, which is where Stapleton et al. locates drought and repeated heat waves, may lead to temporary cyclical migration as communities adapt to seasonal risks or permanent migration depending on how these threats impact local economies. Within this framework repeated sudden onset hazards may lead to long-term permanent relocation as cumulative impacts alter the living conditions in a locality or may promote immobility as populations’ capacities to move are eroded by repeated financial damages (Ibid; Schewel, 2019).

Within the field of migration research, there tends to be more data available on displacement due to sudden-onset hazards due to their salient impacts and discrete timelines, whereas mobility data on emerging effects of slow-onset climate hazards is limited. This trend results in more mobility research being conducted around sudden-onset climate hazards, while slow-onset hazard research has been primarily qualitative and case study-based (IOM, 2021). These qualitative studies have helped provide contextual depth to mobility research, a topic that will be explored further in the theory section below, yet quantitative research is still needed to test findings at larger scales and determine the applicability of trends in different regions (Ibid; Piguet el al., 2018). A recent literature methodology review of climate migration research over the past 50 years found the need for more quantitative, spatial, and multi-level approaches (Piguet et al., 2018). Geospatial studies investigating the cumulative impacts of recent repeated sudden-onset climate stressors may provide insights on how the similarly erosive effects of slow onset hazards may play out on regional human mobility systems in the coming decades.

2.2 Environmental Mobility Theory

While environmental considerations have been incorporated into migration theories since their inception in late 1800's, their influence was considered secondary to economic drivers until growing concern over the implications of climate change instigated a reconsideration in the late 20th century (Piguet, 2011; 2013). Historically, prominent migration theories have linked population movement to geographic differences in supply and demand of labor markets. Early theories were developed from empirical observations of urbanization occurring in the industrial revolution where migration was primarily associated with opportunity availability in city centers (Ravenstein, 1889). Within this framework, economic influences like low wages act as "push" factors, while more diverse and appealing job markets are considered "pull" factors drawing workers from origins to destinations (Lee, 1966; Harris and Todaro, 1970). Over the last century, labor migration theory has evolved to consider more intervening, value-based, social, and structural concerns (Stouffer, 1940; Lee 1966;

Stark and Bloom, 1985). However, in the advent of global warming, many researchers began to question whether the disruptive influences of a rapidly changing climate should be more directly investigated. Attempts to do so have generated disputes within the various fields engaged in migration research but have also stimulated fruitful efforts in condensing related theorizations into the robust, multi-level conceptual frameworks available today (Massey, 1990; Hunter et al., 2015; Piguet et al., 2011; De Haas, 2010).

In the 1980's and 1990's, a series of highly influential publications revitalized the study of environmental factors in human migration, igniting debate around the severity and immediacy of migration impacts related to environmental instability caused by impending climate change. Seminal works included the 1985 United Nations Environmental Programme (UNEP) report by Essam El-Hinnawi, who popularized the term *environmental refugee* and the first Intergovernmental Panel on Climate Change (IPCC) Assessment in 1990 that linked scientific consensus on anthropogenic climate impacts to forecast widespread human migration in response to environmental instability (Black, 2001; Piguet et al., 2011). A number of large predictions were made at this time that catalyzed global concern and largely set the tone of alarmist visions of future environmental refugees in mass migration still popular today (Piguet et al., 2011).

These estimates were widely criticized by researchers across the social sciences for their monocausal simplicity and lack of empirical support (Ibid). This early work was problematized for its lack of connection to classic migration theory and environmentally deterministic approaches that neglected agency and socio-political factors affecting potential migrants, resulting in a stigmatization of migrants from developing countries (Hunter, 2005; Piguet et al., 2011; Wiegel et al., 2019). Critics argued the need to contextualize the investigation of climatic factors amid a multi-causal network of political, economic, and social interacting effects (Massey et al., 1998; Black et al., 2011). Now mostly resolved, the debate helped inform more critical approaches and stimulated efforts to synthesize insights from past migration theories especially in their treatment of environmental conditions which has helped to ground contemporary mobility research.

Within the array of iterative theorizations on migration a distinction might be made to parse theories that support a holistic perspective and help integrate issues of resilience, adaptation, values, and vulnerability into observations around hazard risk and migration potentials, versus, theories that provide conceptual language around environmental tipping points in migration specifically. While the former is explored below to provide framing for research design and interpretation, the latter is discussed in relationship to hypotheses considered in recent wildfire migration work.

2.2.1 Contemporary Immobility / Mobility Theory

Contemporary environmental mobility research has progressed from an accumulation of interdisciplinary exchange between the fields of economics, geography, sociology, anthropology, psychology, international development, and refugee studies. Much of the work to condense and reposition relevant past migration theory with an eye towards environmental treatments is captured within the capacities-aspirations theory as perceived within a mobility-immobility spectrum. This study draws upon the work of Massey, Carling, Black, Schewel, and De Haas, among others to understand the evolution of this theorical framework.

A leading critic of early climate migration research, in the late 1990's Massey developed multi-level, multi-causation analysis as a moderate approach integrating atomized cost-benefit analysis from neoclassical traditions, with micro-scale household strategy from New Economics of Labor Migration (NELM), and macro concepts of political economy from sociology (Massey, 1990). Massey's theory emphasizes interrelationships between social and economic processes across multiple scales and temporalities, engaging with the cumulative or moderating nature of migration pressures and incentives (Ibid). Massey and his collaborators focused on four essential elements of migration theory: push factors from origins, pull factors at destinations, the network of socioeconomic structures that connect origins and destinations, and considerations of the aspirations and motivations of potential migrants (Massey et al., 1999; Schewel, 2019).

In a seminal publication, Black et al. expanded consideration of migration as adaptation via risk diversification from economic models (Stark and Bloom, 1985), by situating Massey's multi-casual framework specifically in the context of climate change (Black et al., 2011). By presenting a multi-casual framework within the conception of a decision-making process where only some outcomes led to migration, this structuring engaged with the idea of immobility where "not everyone is able to migrate" (Ibid). Empirical evidence of involuntary immobility experienced by impoverished populations was emerging in the literature at this time (Carling, 2002). Later codified as the "trapped populations" concept, new thinking acknowledged how underlying socioeconomic vulnerability could be exacerbated by climate change impacts thus inhibiting mobility and buffering the high migration estimates made during the alarmist era (Black et al., 2011).

Findings pointing to the presence of immobility helped identify a bias in migration research in which a focus on drivers and outcomes measured in out-migration had left out considerations of resistance or constraints to migration (Schewel, 2019). Recently researchers have proposed repositioning migration study within a larger consideration of mobility in relationship to immobility using a categorization based on varying combinations of ability and/or desire to migrate (Carling, 2002; De Haas, 2010; Carling, 2018, Schewel, 2019). This categorization creates a multi-directional immobility-mobility spectrum where *mobility* is defined as the condition of having both the aspiration and ability to migrate, *involuntary immobility* as the aspiration but not ability, and *voluntary immobility* as no desire to migrate (Schewel, 2019). Note that mobility in this theory encompasses both voluntary and involuntary mobility, based on reasoning that the decisions rest on the preference to move away from current conditions whether or not the stakes may vary widely (Ibid).

The aspirations-capacities theory is a variation on the above where *capacities* replace the language of abilities so to center an analysis of how development relates to individual finances and thus can increase capacity to carry out migration decisions (De Haas, 2010; 2021). This challenges assumptions that development will alleviate migration push factors in low-income areas, instead highlighting how development can lead to increases in capital, education, and information, cumulatively creating more access to migration if desire is present (Ibid). This distinction between aspirations and capacities may help explain why internal migration is observed to be so much larger than international migration (UNHRC).

Recently, Shewel's work suggests incorporating immobility into De Haas' aspirations-capacities theory, which has yet to consider structural constrictions to move or desire to stay within migration decision processes. The use of capacities ideology makes it easier to imagine the dynamic nature of the mobility-immobility spectrum, where rigid divisions dissolve and instead individuals can transition across categories over time as resources and desires change in relation to the socioeconomic and political contexts of origins and destinations. Schewel's immobility approach offers the new terms *retain* and *repel* to augment the classic push-pull framework, where *retain* represents qualities holding people to an origin whether positive or negative and *repel* refers to perceptions dissuading people from the migration process such as uncertainty or risk aversion. Thus, the immobility model stirs up consideration of actor's agency, along with questions of embeddedness and relational ties (Schewel, 2019) that could be grouped under concepts well understood in planning and design such as land tenure, place attachment, social capital, and place-specific knowledge. In these ways, immobility theory engages with "economic irrationalities" that have challenged neoclassical theory in the past, where rational choice models have failed on social behaviors related to relational capital, gender, and religion (Schewel, 2019). While neoclassical economic models are based on the concept of stasis where mobility requires explanation rather than immobility, immobility theory has similarities to NELM where access to mobility is diverse, falling unevenly due to existing resource inequalities and structural constraints. Constraints to mobility can be political, legal, economic, social, or physical. Increasing mobility restrictions for certain groups (e.g. nationalities) within the contemporary era suggests that migration as adaptation may be seen as a social privilege, characterized by resource access and sociopolitical status (Bauman, 2011; Piguet et al., 2018).

The aspirations-capacity and mobility-immobility spectrum theories provide holistic frameworks to consider how demographic and developmental differences may influence mobility outcomes. A focus on diverse conditions also suggests that underlying differences between developing and developed countries influence the applicability of past international research and posits the need for further research to understand unique conditions of migration systems under climate change within the US.

2.3 Climate Migration in the United States

Much of the existing literature on climate migration and more broadly environmental mobility research is based on empirical studies in developing countries. There have been a number of reasons suggested for this research emphasis towards developing countries and international migration including the priority of greater vulnerability within the Global South, national securitization narratives, and Northern developmental capacities imparting a perceived immunity from climate impacts (Piguet et al., 2018; Hoffmann et al., 2020). Regardless of reason, divergent socioeconomic patterns and development capacities between hazard-prone regions within developing and developed nations suggest that research findings from the Global South may have limited applicability outside their region.

In the context of developed countries, such as the US, greater infrastructure related to disaster response (federal aid programs, insurance, firefighters, emergency response), adaptation (irrigation, energy availability for air conditioning, resilient power system development), and social support programs change the nature of vulnerability in wealthy countries (Davies, 2018). This infrastructure capacity buffers physical risk to some extent in developed countries, where damages due to environmental hazard tends to be measured in economic losses rather than substantial loss of life (Hunter, 2005). When considered in a capacities-abilities conceptual framework, impacts from climate hazards in developed countries like the US are largely decided by underlying socioeconomic status. The structural supports such as insurance and federal aid potential can dampen migration pressure for higher-income households with greater access to these resources or even act as economic incentives to engage with higher levels of environmental risk (Davies, 2018).

The administrative capacity and economic structure of wealthy developed countries such as the US also provides opportunities to define populations of potential migrants and associated methodologies available for measuring these groups. Within the US, there are three types of potential climate migrants: homeowners receiving federal or state support via assisted migration or buy-out programs, evacuees of immediate disaster that eventually permanently relocate, and individuals or households who make the independent decision to move (Urban Institute, 2019). The difficulty for quantifying and tracking the movement of these groups varies depending on their level of official assistance and related procedural documentation; known disaster timelines that can be cross referenced with public data source; or the lack thereof (Ibid).

Within this categorization, disaster evacuees represent a large group that may be more easily studied due to access to information and the rise of extreme weather events across the country. However, there are some limitations to take note of when studying mobility in relation to evacuation estimates. The primary concern is that evacuation figures only provide an estimate of potential displacement. Even when mandatory, not all area residents do or can obey evacuation orders. If individuals or household do relocate it is usually on a temporary basis, often preferring to stay close to home and return as soon as possible (Hunter et al., 2015).

Temporary displacement can result in permanent migration, but these two concepts are, as mentioned, not synonymous. On the other hand, the diverse demographics of those impacted by regional evacuation orders provides an opportunity to examine how a more broad sampling of the population may respond to sudden-onset climate hazards. Thus, scrutinizing the relationship between populations at risk of displacement and populations who move, i.e. migrants, may provide useful insights into how climate hazards are impacting different demographics and where social and infrastructural interventions are needed to support vulnerable communities.

2.4 Wildfire Migration Research in the US

Despite its prevalence in the US landscape, wildfire remains an underrepresented hazard in environmental mobility literature, with recent review articles including no wildfire-focused research (Hoffmann et al., 2020; Hunter, Luna, Norton, 2015; Piguet et al, 2018; McConnel et al., 2021). Similarly, this study did not find representation of wildfire-related work within the literature review components of theory and empirical synthesis articles consulted here (Findlay, 2011; Kaczan and Orgill-Meyer, 2019; De Haas, 2021). Environmental mobility research in the US to date has focused on hurricanes with an abundance of empirical insights available on displacement and migration surrounding major storms in the Gulf of Mexico (Curtis et al., 2015; Bleemer and Klaauq, 2019). While these studies build understanding around environmental mobility in the context of the US, the socioeconomic conditions relating to federal aid for major disasters often available to hurricane-impacted communities and development patterns in coastal areas are quite different than that of wildfire.

Within the past few years, studies have begun to address the gap surrounding wildfire migration research in the US by tracking evacuation related displacement (Jia et al., 2020), documenting migration response associated with disaster-level wildfires (Winkler and Rouleau, 2020), subsets of megafire (Sharygin, 2021), and destructive wildfires (McConnell et al., 2021). The findings and diverse methods utilized within these recent studies have informed the approach and interpretation of results in this thesis.

Using Facebook Disaster Maps, Jia et al., tested a novel big data methodology to track evacuation displacement surrounding two megafires in California during 2018. The study compared results between the Mendocino Complex, a high acreage/low destruction fire that took place in Northern California, with the Woolsey fires which were lower acreage/high destruction that took place in Los Angeles and Ventura counties. For comparison, the Mendocino complex was the largest fire by burn area on California record at the time, burning more than 459,123 acres (since unseated by larger fires in 2020 and 2021) and destroyed 280 structures, while the Woolsey fires destroyed over 1,600 structures making it the 8th most destructive fire on California record (Phillips, Kaplan, and McMillan, 2018). The study used Facebook Disaster Maps (FDM), a social media data source that maps changes in anonymous Facebook login locations in relation to a disaster timelines, here set as the beginning of evacuation orders versus the lifting of those orders. The authors compared the Facebook login rate to two population estimates, one from the American Community Survey (ACS) at zip code level and Gridded Population of the World dataset from Columbia University, to calculate the representativeness of the data as compared to total area population. The data was found to be more representative in urbanized areas and with younger populations, creating limitations for application in rural wildland urban interface (WUI) areas where wildfires often take place. Hot spot analysis was used to detect locational anomalies of logins as compared to pre-wildfire trends and effectively track displacement spatially at a fine temporal scale. Broadly, results indicated slight variation in population return patterns after the lifting of evacuation orders between more urban areas better connected by transportation infrastructure versus rural areas. Where more gradual or low recovery occurred, login change showed relocation to nearby neighborhoods. (Jia et al., 2020)

Sharygin also examined the impacts of a recent major fire complex in California, comparing estimates of wildfire displacement to migration after the Tubbs fire in Sonoma County in 2017 (Sharygin, 2021). Displacement estimates were developed by multiplying the county average persons per household by the number of homes destroyed acquired from state fire agency damages reports. Migration impacts were evaluated using public school transfer data for school attendance zones impacted by wildfire-related housing destruction. Results found only 9% of displaced persons crossed jurisdictional boundaries and most often moved to nearby areas within the same county. Discussion of results considered the limitations introduced by generalizing the behavior of families to all area residents, stating that households without school-age children may display different migration decision making patterns not accounted for in this methodology. Overall, the study's results, as well as those observed by Jia et al., indicate short-term recovery, a predominance of local moves for impacted households, and little to no interregional out-migration in response to wildfire disaster incidents. Similarly, studies of migration systems impacted by major hurricane events along the Gulf Coast have indicated long-term trends of recovery migration through concentrated intraregional population returns and new in-migration (Curtis, 2015). However, it may be noted that the brief timeframe used in these wildfire studies may limit observations on longer migration patterns.

In attempt to capture broader patterns in migration response to wildfire hazard events, Winkler and Rouleau studied all FEMA-designated disaster level wildfire events in the US across the 25-year time period of 1990-2015. The authors include a 1-year lag period for migration effects by utilizing the IRS Statistics of Income (SOI) database as a source for migration estimates. SOI migration estimates are produced by aggregating changes in households' tax filing locations from one year to the next at the county or state level, thereby providing a time horizon that may encompass delayed post-fire migration responses. Spatial relationships of affected counties were organized hierarchically using a dummy variable where 1 represented a county that neighbored a disaster wildfire, 2 represented a county that experienced a disaster wildfire, and 3 represented a county that both neighbored and experienced a disaster wildfire within the year. Findings indicated that disaster-level wildfire had a significant effect on migration rates, however destinations were primarily limited within the region. Counties with fire showed the highest effect on migration rate due to sharp increases in out-migration, counties adjacent to those experiencing wildfire shows the second highest effect based on increased out-migration and a slight decrease in-migration, while counties that both experienced fire while neighboring fire show a lessened effect with decreased in-migration and no observable effect on out-migration. Authors theorized that the low out-migration observed in the group of counties experiencing while neighboring fire may be due to residents' reduced outlook on options since often people relocate to nearby areas. (Winkler and Rouleau, 2021)

The study specifically analyzed migration response in metropolitan versus non-metropolitan counties to test for divergent effects in rural counties where existing migration systems are dominated by the attraction of natural amenities. The authors developed this comparison to test for evidence of a shift in public perception of natural amenities to dis-amenities based on rising climate risks. Amenity theory, initiated by the work of Ullman, has typically treated the environment as a pull factor, however this recent reframing of potential dis-amenities now creates space for consideration of climate change as a push factor (Piguet, 2011; Winkler and Rouleau, 2021). Findings linked wildfire in high natural amenity counties with reduced net migration by 41% more than impact seen in the global model, suggesting that rural WUI areas are currently more susceptible to mobility impacts. Yet, as migrants were found to relocate nearby to intraregional counties with wildfire risk, the data did not substantiate the hypothesis that an amenity to dis-amenity perception shift is yet underway. However, findings also included a strong relationship between homeownership and immobility, where homeownership was shown to damper out-migration rates. This relationship may be influenced by the limiting of data to only disaster-level wildfire events, which trigger federal recovery assistance that often requires homeowners to rebuild in place thus promoting immobility (Winkler and Rouleau, 2020).

McConnell et al., revisited the amenities to dis-amenities shift hypothesis with a focus on how destructive fires influence mobility outcomes through impacts on household finances. The study compared in and out-migration of census tracts experiencing destructive wildfires to their untreated neighbors for a full universe of US wildfires during the 21-year period of 1999 to 2020 (McConnell et al., 2021). Destructive fires were defined as wildfires destroying a minimum of one structure, using data derived from the US National Incident Management System/Incident Command System (ICS) managed by US Department of Homeland Security, which provides counts of structures destroyed or damaged per natural hazard event (Ibid.).

Results showed elevated levels of out-migration for the most destructive wildfires, though no significant effects on in-migration rates (McConnell et al., 2021). These findings contrast from non-wildfire sudden-onset research showing little impact of such events on migration, instead supporting the migration effect related to disaster-level fires as seen in Winkler and Rouleau's work. No substantial recovery migration was found over a period of 2 years post-event for highly destructive wildfires. For less destructive wildfires, no substantial change in migration rates was detected. Where out-migration was observed, relocation is made to nearby fire-prone areas within the original event's region. The authors suggest these findings further disprove the hypothesized dis-amenities shift for now, though do not negate a potential future threshold may be impacted by continuing large scale fire (McConnell et al., 2021). To this point, 7 fires occurring in the years 2020 and 2021 have been in the top 20 most destructive fires on California record, suggesting a continuing trend and opportunity for study.

The study's demographic findings on wildfire impact on personal finance were estimated based on quarterly reports from the Federal Reserve Bank of New York/Equifax Consumer Credit Panel. There were a number of notable trends that support the link between high-income, mobility capacity, and migration outcomes. Residents over 60 years old and those in the high-credit score brackets were found to be most likely to migrate. However, elderly populations were also more likely to shift from homeowners to renters within the post-fire study period. These findings indicate that the most destructive wildfires have substantial impacts on personal finances, shifting housing decisions and increasing potential residential transition in ways that may affect housing availability repercussions for area renters. (McConnell et al., 2021)

What the above wildfire migration studies have in common is a focus on the major fires, as destructive and disaster-level events. McConnel et al., acknowledge that this focus effectively excludes livelihood effects from fire damage to valuable, productive lands not associated with buildings such as managed forests and agricultural lands (McConnell et al., 2021). The authors also acknowledge how disaster recover funding, whether for in-situ adaptation or simply rebuilding, can dampen migration for impacted homeowners. The focus on disaster level and/or majorly destructive fires may obstruct observation of diverse mobility responses by inherently prioritizing homeowner populations. Additionally, each study uses a relatively short time horizon for measuring risk exposure, limiting the examination of migration impacts to single fire events or single fire complexes. There remains an opportunity to study migration related to a broader scope of wildfires impacts, such as on potential displacement via evacuation estimates, and time frames. By and in large the above studies suggest that wildfire impacts are not precipitating observable large-scale migration effects at this time. Longer term observations such as related to cumulative impacts of repeated fire events may provide a new approach to perceiving wildfire-related mobility patterns.

CHAPTER 3. BACKGROUND

Studying environmental mobility in relation to a given hazard type (e.g., wildfire) requires a fundamental understanding of the landscape conditions that define the scope of environmental risk associated with that hazard as well as the social context that influences its impacts and mobility outcomes. While migration research related to wildfire in the US remains relatively underdeveloped, literature on the ecological and social conditions related to wildfire hazards, wildfire mitigation planning, and community response is expansive. This section reviews background information on wildfire risk to provide a context for examining environmental mobility systems related to wildfire hazards in the western US.

The section begins by defining the basic ingredients of wildfire, then explores a history of cultural factors that have driven the recent increase in wildfire risk. Land management practices, development patterns associated with existing migration systems, and anthropogenic climate change are understood to be interacting and aggravating the essential components of wildfire risk. Finally, socioeconomic demographics of fire-prone landscapes in the western US are discussed to understand how variability in hazard vulnerability, adaptive capacity, and landscape values influence community preparedness planning and wildfire impacts that affect potential migration response.

3.1 Wildfire Risk and the Wildlands-Urban Interface

Wildfires pose a threat to human life, health, and livelihoods via potential destruction or damage to homes, communities, personal finances, natural resource economies, and real estate values. Damages can also come from wildfire aftereffects such as regional air quality degradation from smoke, water quality degradation from stream sedimentation, and post-fire landslides (Barbero et al., 2015). Over the last four decades, the number of destructive wildfires, acreage burned, and economic impacts from damaged structures have grown exponentially in the US (Buechi et al., 2021). The length of wildfire season and spatial extent of at-risk landscapes have grown substantially since the 1990's, expanding environmental risk for many populations in the US (Balch et al., 2016). Recent increases in wildfire damages and risk are not considered anomalous but a trend resulting from a combination of historic forest management practices, development patterns, and the growing influence of climate change.

The essential components needed to start a wildfire are fuel, ignition source, and desiccation, (i.e., dryness) (Buechi et al., 2021; Balch et al., 2016). Fuel describes flammable vegetation, ignition comes from lightning strikes or human sources, and dryness levels are measured by vegetation and soil moisture rates (Ibid). Historic and current land use trends have contributed to growing wildfire risk by altering these ingredients with historic landscape management practices increasing fuel availability, exurban development patterns increasing human vulnerability to fire-prone ecosystems, and increasing human ignition sources in the landscape (Marlon, 2012; Balch et al., 2016). Additionally, climate change is understood to be increasing the flammability of vegetation by increasing drought conditions which in turn influences fuel aridity (Abatzoglou and Williams, 2016).

3.1.1 Landscape Management and Fuel Accumulation

When discussing wildfire risk in the US, it is important to keep in mind that wildfire is native to the ecology of many western US landscapes. Historic changes in wildfire rates have typically followed climatic shifts in temperature and aridity (Marlon, 2012). Historically Native American communities lived with and used fire in the landscape to clear land for agriculture and hunting, practices well documented in ethnographic research and now understood to reduce risk of catastrophic fires (National Park Service, 2023; Anderson, 2005). The prevalence of more intense and destructive wildfires over the last century is now largely attributed to modern, western landscape management practices of fire suppression that have led to fuel loading, i.e., increasing availability and density of flammable vegetation, in naturally fire-prone landscapes (Radeloff et al., 2018). Milestones of the fire exclusion paradigm included the establishment of the US Forest Service in 1905 under the mission of extinguishing fire on publicly reserved land, growth of fire management by the National Park Service in 1916, and expansion of total fire suppression in the 1940's (Cohen, 2008). Fire policy in this era was characterized by fire suppression to the greatest extent in the name of protecting federal forest resources and private property (Ibid). Researchers now describe the retrospective effect of the removal of natural fire from the landscape as a 'fire deficit' that is contributing to large acreage fires in the West today (Marlon, 2012; Parks et al., 2015).

In the 1970's, the fire exclusion campaign ended as the ecological role of fire in the landscape was recognized and incorporated into restoration techniques such as thinning and controlled burning. Today, fire management on public lands is characterized by a dynamic albeit contested balance of forest management practices that attempt to restore diverse forest structure and support self-sustaining ecological processes that decrease risk of severe fires while balancing timber harvesting and working within constraints imposed by current human development patterns (Noss et al., 2006, Ryan, 2013). Contemporary fire management and mitigation efforts lean heavily into an understanding of fire-adaptive landscapes for both ecological and human communities.

3.1.2 Wildland-Urban Interface, Amenity Migration, and Ignition

Increasing wildfire risk in the US is deeply related to population de-concentration development patterns. Since the 1940's interregional migration trends have shown population movement towards the western and southern US and away from the Northeast and Midwest (Hammer, Stewart, and Radeloff, 2009). Much of the migrating population has resulted in suburban and exurban sprawl into wild landscapes in a development pattern known as the wildland-urban interface (WUI), which has greatly increased human vulnerability to fire risk due to proximity to flammable vegetation (Ibid; Stewart, 2007) Amenity driven migration is a significant component of recent WUI expansion, as population growth in rural, i.e. non-metropolitan, counties has be shown to be closely related to natural amenities (McGranahan 1999). Mountainous western and exurban counties with abundant open space amenities have seen the fastest population growth in recent decades, displaying a shift in economic value of environmental amenities from resource for production to real estate value (Chen et al., 2009). Between 1990 and 2010, the WUI was the fastest expanding land use type in the contiguous US, growing by 41% in new housing and 33% in land coverage over the span of two decades (Radeloff et al., 2018).

The growth of the WUI affects fire risk and impacts in a number of ways, (1) by increasing the risk to human life by proximity to fire-prone landscapes, (2) by increasing the chances of destructive fires with more toxic smoke due to burning building materials, (3) by increasing potential human ignition sources in wildland adjacencies, (4) creating a land use pattern that makes fire more difficult and expensive to fight (Radeloff et al., 2018; California Air Resources Board, 2021). As a consequence of expanding settlement in and around wild landscapes, the majority of wildfires in the US are now human-started, accounting for 84% of wildfires and 44% acres burned between 1992 and 2012. While lightening-ignited wildfire remains more prevalent in the mountainous western US, the incidence of human ignitions has effectively altered the fire niche. Human-ignited wildfires have expanded wildfire season by 3 months and the spatial extent of fire-prone landscapes in areas of traditionally higher fuel moisture as compared to the seasonality and conditions of lightning-ignited fires (Balch et al., 2017). However, these finding do not suggest that human ignitions are primarily responsible for recent increases in wildfire over the US landscape but that human ignitions aggravate underlying conditions affected by climate change and fuel loading. Research indicates that warming trends related to climate change are resulting in earlier springs and extending the fire season are increasing the frequency of both human-ignited and lightening-ignited fires in the western US (Ibid).

3.1.3 Wildfire and Climate Change

When studying the relationship between climate and wildfire, researchers look at the effects on fire regimes, i.e., patterns of fire occurrence in terms of size, severity, frequency, variability, and seasonality in a given area or ecosystem over time (Agee, 1998). Change to fire regimes is influenced by characteristics of fuel availability such as amount, arrangement, contiguity; and the flammability of fuels affected by moisture content and chemical composition (Littell et al., 2016). Climate can influence wildfire by altering the abundance of fuel (i.e., vegetation) and its flammability due to change in moisture (atmospheric, soil, foliage, and surface moisture) (Ibid). While historically drought has led to increased wildfires and anthropogenic climate change is predicted to exacerbate drought in frequency, severity, and duration; the relationship between wildfire and current climate change is complicated by a host of interacting stressors that could accelerate or moderate impacts to varying extents with wide regional variation (Little et al., 2016). Ecological uncertainties revolve around abundance and type of vegetation, including factors of tree mortality, change in species composition, insect and invasive species distribution, while cultural factors include land management practices and water demand (Ibid).

Looking more narrowly at the issue of flammability, anthropogenic climate change has been linked to increased fuel aridity, escalating the flammability of fuels across the US, with researchers estimating that roughly half of the increased burn area since the 1970’s is due to a warming climate (Abatzoglou and Williams, 2016). Climate change is expected to increase the potential for wildfires and burn area by both the severity of fire-prone conditions and expansion of the fire season in number of days which are conducive to fire activity (Barbero et al., 2015). The largest increase in fire danger is projected for the western US due to a combination of increasing temperatures and decreasing rainfall and humidity (Ibid). The increased potential for very large fires in the era of climate change may strain fire-suppression resources both financially and by stretching man-power capacity for firefighting (Ibid). This strain of resources may result in greater destruction and smoke impacts felt across western regions, questionably influencing migration outcomes beyond the locality of wildfires themselves. As such, this paper engages with the question of whether the effects of climate change-aggravated wildfire risk are significant enough to alter existing landscape preferences and migration systems. Addressing this question requires not only an understanding of ecological or physical wildfire risk but the socio-economic context that defines human vulnerability to wildfire risk, perception of risk, and response to risk including engagement with preparedness planning.

3.2 Demographic Context, Adaptive Capacity, and Vulnerability

Growth of the WUI land use pattern has raised concerns over who bears the responsibility of fire risk mitigation as public land management agencies navigate the increasing financial burden of fire fighting for wildlands and adjacent private property (Stewart et al., 2007; Paveglio et al., 2008). Wildfire mitigation now requires individual and collective community action, yet preparedness planning is complicated by the diversity of community types that occupy geographically discontinuous patches of WUI (Paveglio et al., 2015). Community wildfire preparedness planning is often described under the banner of fostering *firewise* or *fire-adapted communities* (FACs), defined by collective planning to mitigate or build resilience to wildfire risk in ways that reduce loss of life and property (FACC, 2022). A major aspect of FACs planning is the establishment of community wildfire protection plans that identify local areas of high risk and methods of risk reduction such as reducing vegetation surrounding structures, creating fire breaks, and implementing adaptive building codes (Ibid). These practices are meant to build communities' adaptive capacity, a term used to describe the potential or ability to perceive, evaluate, manage, and adjust to potential threats; take advantage of opportunities; or respond to consequence (Wall and Marzall, 2006; IPCC, 2022).

There are a variety of issues related to perception of risk and capacities that influence individuals, households, and community manner of engagement in adaptive wildfire planning such as prior wildfire experience, ecological and local landscape knowledge, access to information, willingness to collaborate, trust in government, community identity, land tenure, and income (Paveglio et al., 2015). Amenity driven migration contributes to social diversity in fire-prone western landscapes, characterized as a demographic transition between the Old and New West communities once defined by resource extraction economies such as forestry and mining become dominated by service-based industries including recreation and tourism (Winkler et al., 2007). New and Old West communities often have widely varying values associated with environmental management as well as levels of place-based knowledge and capacity to alter their local environment for fire risk mitigation (Ibid). The same network of issues are at play within wildfire mitigation and preparedness planning, providing understanding of the social context of wildfire vulnerability, diversity of adaptive capacities, and values that influence migration decisions and mobility outcomes related to wildfire.

Response to wildfire and mobility outcomes are both also dependent on an individual or household's quality of vulnerability to natural disaster. Hazard vulnerability is described as exposure of underlying socioeconomic systems to a natural disaster such as wildfire and that system or individual's adaptive capacity to "absorb, recover, and modify exposure to the hazard" (Davies et al., 2018). While wildfire-prone areas tend to be inhabited by higher income households, low-income households that do live in at-risk urban peripheries have higher hazard vulnerability (Ibid). People with lower resource accessibility may find the continuous costs for insurance and landscape maintenance for fire risk mitigation such as tree trimming, thinning, and brush removal prohibitive. When fire does impact lower-income populations, who are more likely to rent, they are often ineligible for federal assistance available to homeowners for rebuilding after a fire event (Davies et al., 2018).

Wildfire hazard vulnerability may also influence mobility in its intersection with the non-local impacts of smoke, a connection that has been hard to spatially measure and thus quantify. An estimated 9% of US population live in areas with "very high potential" for high intensity wildfires, yet a much larger segment of the population is impacted by smoke effects (Dillon and Fay, 2015). While fire mitigation primarily focuses on protecting homes and developed areas, the health impacts of wildfires that do not threaten structures could also be detrimental, especially when burning at large acreages (Burke et al., 2021). Recently, medical researchers estimated that climate-change induced wildfire smoke could increase mortality rates beyond temperature-related mortality (Ibid). Such projections suggest the need for greater consideration of the downstream impacts of wildfire on larger populations including urban adjacencies.

CHAPTER 4. METHODOLOGY

This study tests the effect of wildfire displacement events (i.e. evacuation events) on direct measures of county-level out-migration from the IRS Statistics of Income Migration Program over the tax years 2016-2019. Contemporary environmental mobility and modern migration theory identifies the household as the migration-decision making unit (Massey, 1990, Odland and Ellis, 1988; Stark and Bloom, 1985). Following precedent in the literature, the measure of household out-migration rate was chosen as the dependent variable for modeling. The household out-migration rate was calculated by number of households out-migrating out of a given county as a percentage of the total households in that county (i.e. all households at risk of out migrating). Out-migration rate was calculated for each county within the study region, for each year within the study period.

To observe the potential effects of repeated wildfire hazards over the 4-year study period, a panel dataset was developed by combining time-series data of wildfire displacement events and out-migration rates with cross-sectional data on county-level socioeconomic demographics representing additional descriptive and independent variables. Wildfire displacement events are represented by dummy variables, an approach based on precedent in recent climate migration research (Winkler and Rouleau, 2020). A pooled ordinary least squares (OLS) multivariate model was chosen as the primary analytical method to explore the relationship between repeated wildfire events and out-migration rates over time, amid several competing explanatory variables known to be related to mobility. The pooled OLS regression model is commonly used as a baseline model when working with panel data. Due to time limitations of the study, the pooled OLS model was chosen as a starting point, with the possibility for further analysis using additional modeling techniques in the future.

The broad goal of this study was to develop an accessible methodology for testing the effects of a repeated sudden onset climate stressor on out-migration rates in the context of a developed country such as the US. Repeated sudden onset climate stressors potentially represent a climate change variable that blurs the boundary between sudden and slow onset stressors via frequency and cumulative impact. By this logic, the study of repeated sudden onset stressors may provide foresight into how anticipated slow onset stressors may impact migration response in local populations within the US. Preparation of the panel dataset integrating hazard, migration, and socioeconomic data at the county-level was a large portion of the study's work and is intended to provide continue research opportunities via a shareable dataset. The section below offers more detail on the sources of data and workflow carried out to compile the dataset used in this study.

4.1 Wildfire Displacement Event Data

Wildfire displacement event data was obtained from the Internal Displacement Monitoring Centre (IDMC). While there are numerous sources for wildfire data that provide information on acres burned, areas impacted, and building destruction; IDMC data is novel in its focus on quantitative reporting of broader, potentially impacted populations, beyond only disaster-affected homeowners. The IDMC is a research organization providing multi-source estimates for human displacement caused by conflict and environmental events throughout the world. Event-based monitoring is provided at national scales via the IDMC's Global Internal Displacement Database (GIDD) with the goals of evaluating recent and historic displacement trends, building regional projections, and supporting data-informed policy (IDMC, 2021). Disaster event-based displacement monitoring records include information on the region of event incidence, hazard name, hazard category (i.e. weather-related), hazard type, start date, and displacement estimates.

IDMC displacement estimates are based on data acquired from local authorities, humanitarian organizations (non-governmental organizations, civil society organizations, private sector), research institutes and academia, and media sources. More recently, new data methods including remote sensing via satellite imagery, natural language processing, and machine-learning have been utilized to identify displacement events and validate other traditional sources as mentioned above. Procedurally, IDMC displacement estimates are derived using a weighted scale relative to the validity of primary data sources, as informed through historic precedence of verifiability and accuracy. Information from government, local authorities, and humanitarian clusters are prioritized. Data from international and/or local NGO's, human rights groups, and academia are used as supplement and where priority data sources are unavailable. Media sources are used only when primary and secondary data sources are unavailable or as means to triangulate higher tier sources. Reliability in estimates is authenticated via this multi-source triangulation and estimates are generally considered conservative. (IDMC Disaster Codebook, 2017; IDMC, 2022)

The IDMC has provided event-based monitoring for a range of weather-related human displacement events in the US since 2013. Within the US, displacement information is collected from the Federal Emergency Management Agency (FEMA) daily situational reports on evacuation orders and housing damage reports, the American Red Cross on emergency shelter reports, local and state emergency management offices, and local news media sources. Where housing damage data is included, reports on number of destroyed homes are multiplied by the event country's average household size to determine estimations of individuals displaced (IDMC, 2022). In 2017, the IDMC began providing state location data within their displacement data for the US. In 2018, county locations were added. With the inclusion of these locational attributes, IDMC displacement estimates can now be more readily mapped and analyzed in comparison to migration data.

4.1.1 IDMC Data Preparation & Dummy Variables

Weather-related displacement event data for the US was acquired from the IDMC website in a Microsoft Excel Worksheet format. The acquired data was reduced to wildfire events within only western US counties during the years 2015-2020. Here, western counties refer to those within the states of WA, OR, CA, ID, NV, UT, AZ, MT, WY, CO, and NM. The 2020 wildfire data was ultimately removed from the study due to the inaccessibility of SOI migration data for the 2020-2021 tax cycle, despite an expected IRS release date of November 2022. However, 2020 wildfire displacement event data was prepared and remains available for future addition as more SOI data becomes available.

Wildfire events for years 2015-2017 listed within the IDMC database required additional research and manual addition of county location. County locations of wildfire displacement events were collected via wildfire incident reports, local news stories on evacuation orders, and cross referenced with historic fire perimeter spatial data from the National Interagency Fire Center (NIFC, 2021). State and county Federal Information Processing System (FIPS) codes were added to all events as a join field for mapping and dataset compilation.

IDMC data for years 2015-2019 was cleaned and wrangled using the open-source, statistical software R. Wildfire data was converted from a list of events to a multiyear data table organized by county unit. By doing so the wildfire data was formatted into a time-series displaying a count of all wildfire displacement events occurring per year per county (“FireCntPerYr“) for years 2015-2019. The wildfire data was then joined to a full universe of western counties using a FIPS county codebook, creating a dataset with all 414 western counties represented. Counties without fire events were coded as 0 for each year in the FireCntPerYr variable. A lag variable (lag1) was created based on the annual fire count per county (FireCntPerYr), where 1 represents a fire within the previous year and 0 represents no fire in the previous year. After the lag variable was created, the 2015 wildfire event data was removed, leaving a study period of 2016-2019. The annual fire count per county (FireCntPerYr) and lag variable (lag1) were then used to create a dummy variable (FireTypes) to represent the incidence of repeated wildfire displacement as follows.

Table 1. FireTypes Dummy Variable Conditions

CODE	DESCRIPTION	CONDITION
0	No fire during county-year	FireCntPerYr = 0
1	1 fire during county-year	FireCntPerYr > 0
2	Repeated fire (includes multiple fire events within year and consecutive fire for 2 or more years)	FireCntPerYr > 1 AND/OR FireCntPerYr >= 1 and lag1 = 1

The FireTypes dummy variable was developed as the explanatory variable for modeling, representing repeated and consecutive wildfire displacement event incidence. Within the FireTypes dummy variable (i.e. a multi-level factor), 0 represents county-years not experiencing fire events within that year or the previous year, 1 represents county-years with one fire and no fire in the previous year, and 2 represents county-years with multiple fires within the year or with at least one fire event that year and fire within the previous year. Additionally, a dummy variable representing a binary for any fire (“FireTreat”), i.e.

county-years experiencing any wildfire displacement events (one or more), was created where 1 represents FireCntPerYr > 0 versus 0 representing FireCntPerYr = 0.

Table 2. List of Dummy Variables Prepared

VARIABLE	DESCRIPTION
FIRETREAT	County-years experienced any fire during study period
FIRETYPES	Categorizes county-years by no fire, one fire, or repeated wildfire events occurring within the year or consecutively

Displacement estimates (number of individuals potentially displaced) were aggregated per year for each county ("DispYr"). This variable was prepared to represent the magnitude of displacement events and is available for future modeling to assess the relationship between magnitude of displacement and out-migration. It is suggested that this variable should be standardized by total population at risk of displacement for future modeling (i.e. DispYr as a percentage of total county population). The annual fire count per county (FireCntPerYr) was summed for the full 4 years to create a variable representing the sum of all wildfire displacement events per county across the study period ("SumFires").

Table 3. List of Wildfire Summary Variables Prepared

VARIABLE	DESCRIPTION
SUMFIRES	Sum of all wildfire displacement events in county during study period (2016-2019)
DISPYR	Displacement estimates for all events within county aggregated per year
FIRECNTPERYR	Number of fires in county per year

Wildfire variables were mapped in ArcGIS Pro to observe the spatial distribution of treatment groups (see p. 41 - 44) While there is some evidence of spatial clustering in the FireTreat fire treatment group, especially in California, which is to be expected given the prevalence of wildfire within the state (NIFC, 2021), overall wildfire events appear to have a representative spread across the western states. The spatial distribution of the further disaggregated FireTypes variable shows a similar pattern for no fire versus single fire and repeated fire counties. California is strongly represented within the dataset. However, the annual maps of county-years per FireTypes (p. 39) shows less activity in California during years 2016 and 2017.

Some questions remain as to how clustering may be influenced by the relationship of evacuations to density of development and if this may skew results. This consideration of density of development is addressed by standardizing the migration rate by full population of households within the county and including completing independent variables representing county metropolitan status.

The use of dummy variables to define treatment groups within the study area of the Western US creates the condition of comparing counties experiencing fire to their neighbors not experiencing fire. While this study has based its use of dummy variable format on precedent within recent wildfire migration literature (Winkler and Rouleau, 2020; McConnell et al., 2021), some potential limitations of this approach must be discussed. The recent McConnell et al. article, which identified fire treatment census tracts using wildfire burn perimeters in comparison with neighboring tracts (via queen contiguity selection), acknowledges how using neighboring tracts as control groups does run the risk of skewing results based on spatial spillover effects (McConnell et al., 2021). Within the context of wildfire-related migration, smoke may produce spillover effects on migration decision. McConnell et al., remark that not controlling for spillover effects may lower the overall observed out-migration effects, but this concern was not support by findings which showed appreciable difference in migration rates between treatment groups (Ibd.).

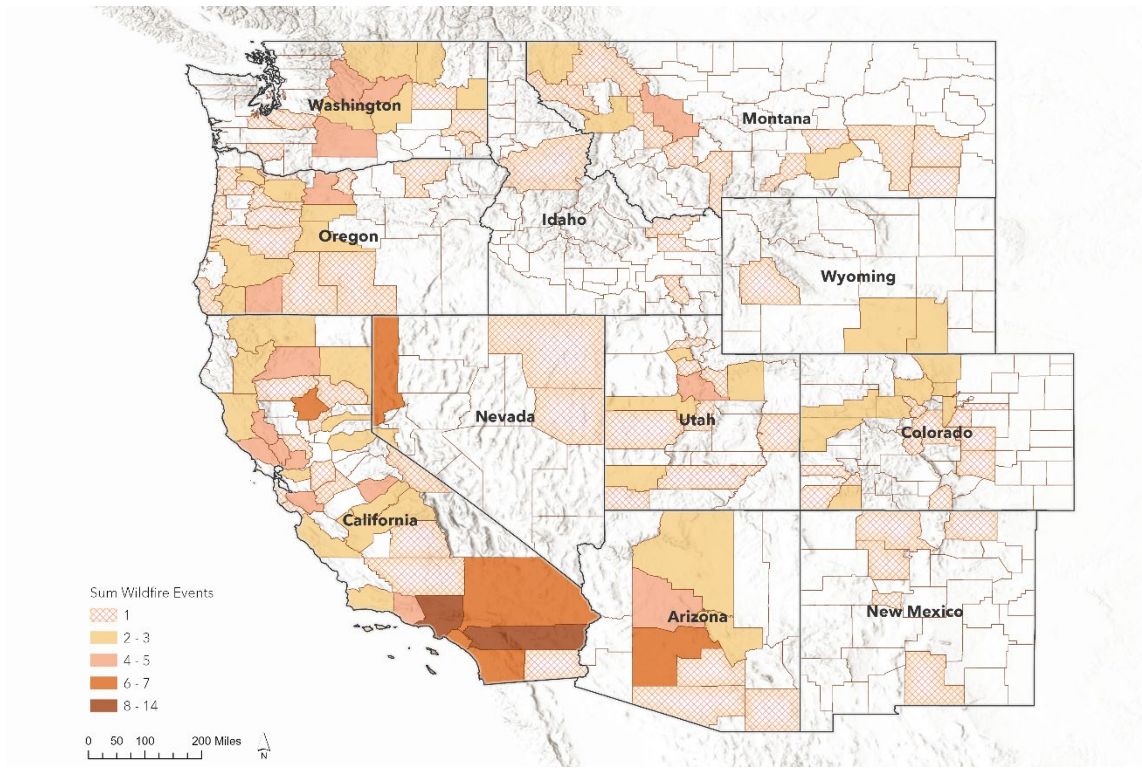


Figure 1. Spatial Distribution of SumFire: Count of wildfire displacement event incidence per county over study period 2016-2019 (Data Source: IDMC, 2020)

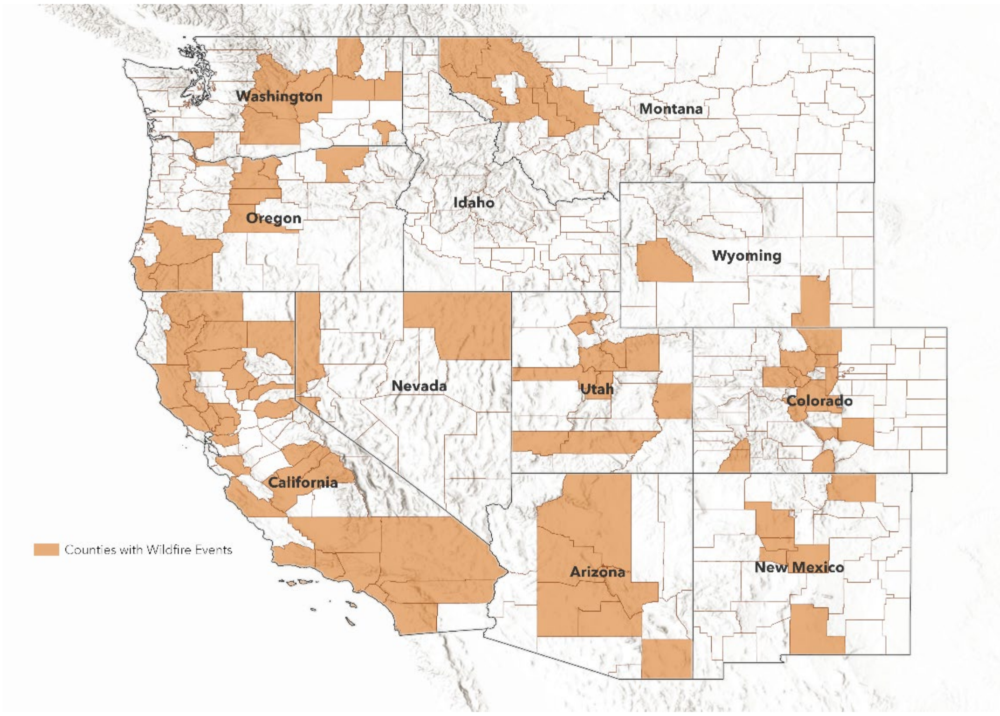


Figure 2. Spatial Distribution of counties within FireTreat groups

Table 4. Frequency count of treatment groups in FireTreat variable

FireTreat	n (county-years)
no fire	1471
fire treatment	146

Source: IDMC, 2020

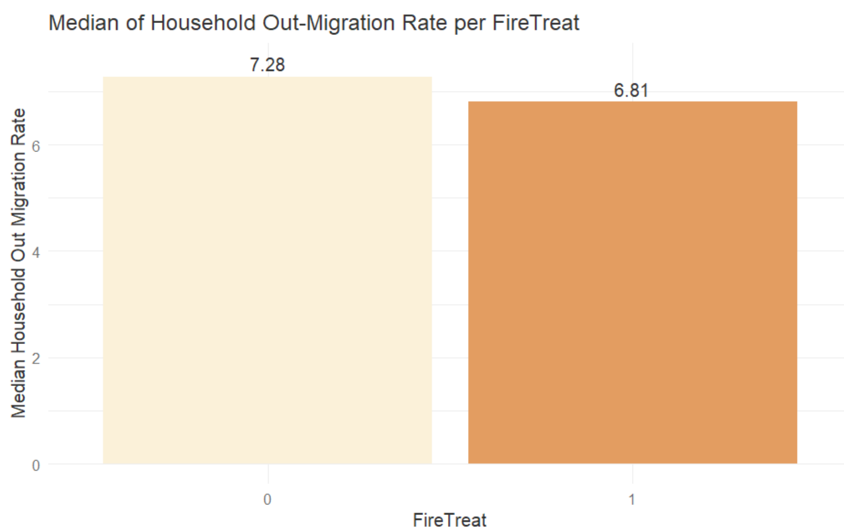


Figure 3. Median Household Out-Migration Rate per FireTreat groups

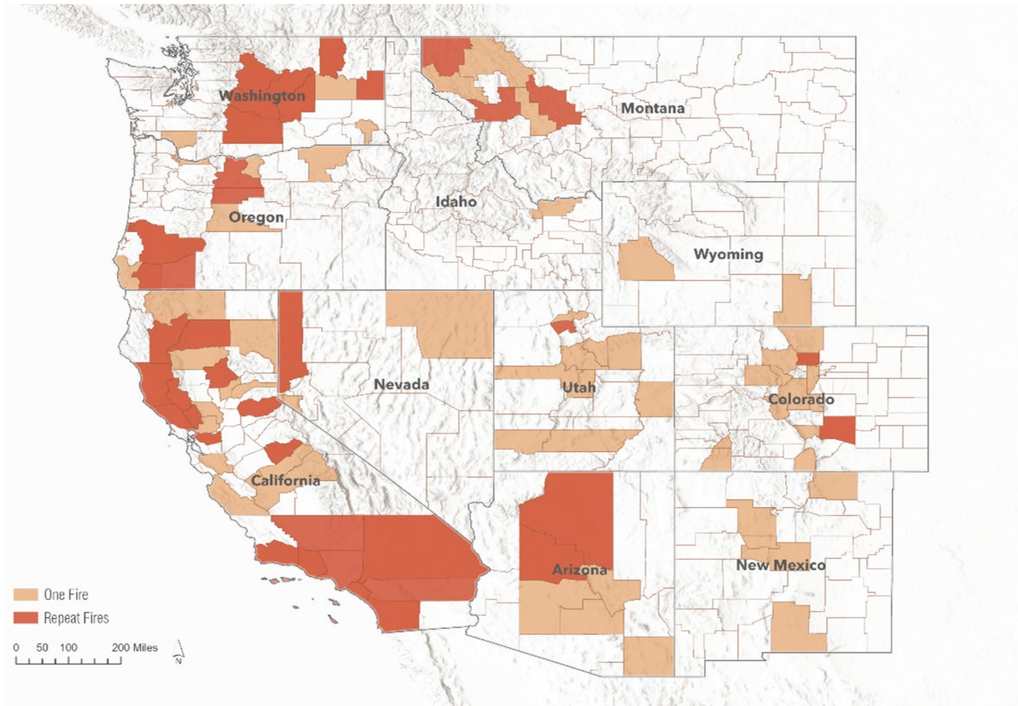


Figure 4. Spatial Distribution of counties within FireTypes groups

Table 5. Frequency count of treatment groups in FireTypes variable

FireTypes	n (county-years)
No fire	1471
One fire	93
Repeated Fire	53

Source: IDMC, 2020

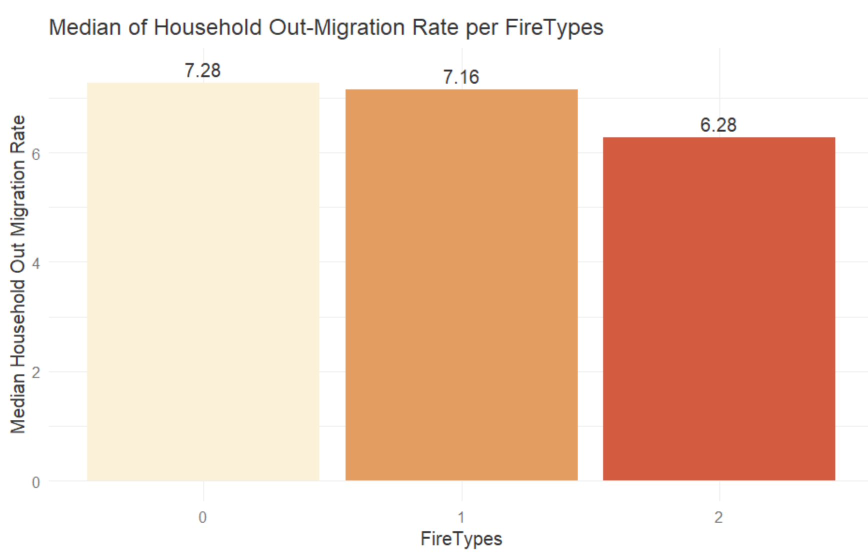


Figure 5. Median Household Out-Migration Rate per FireTypes groups

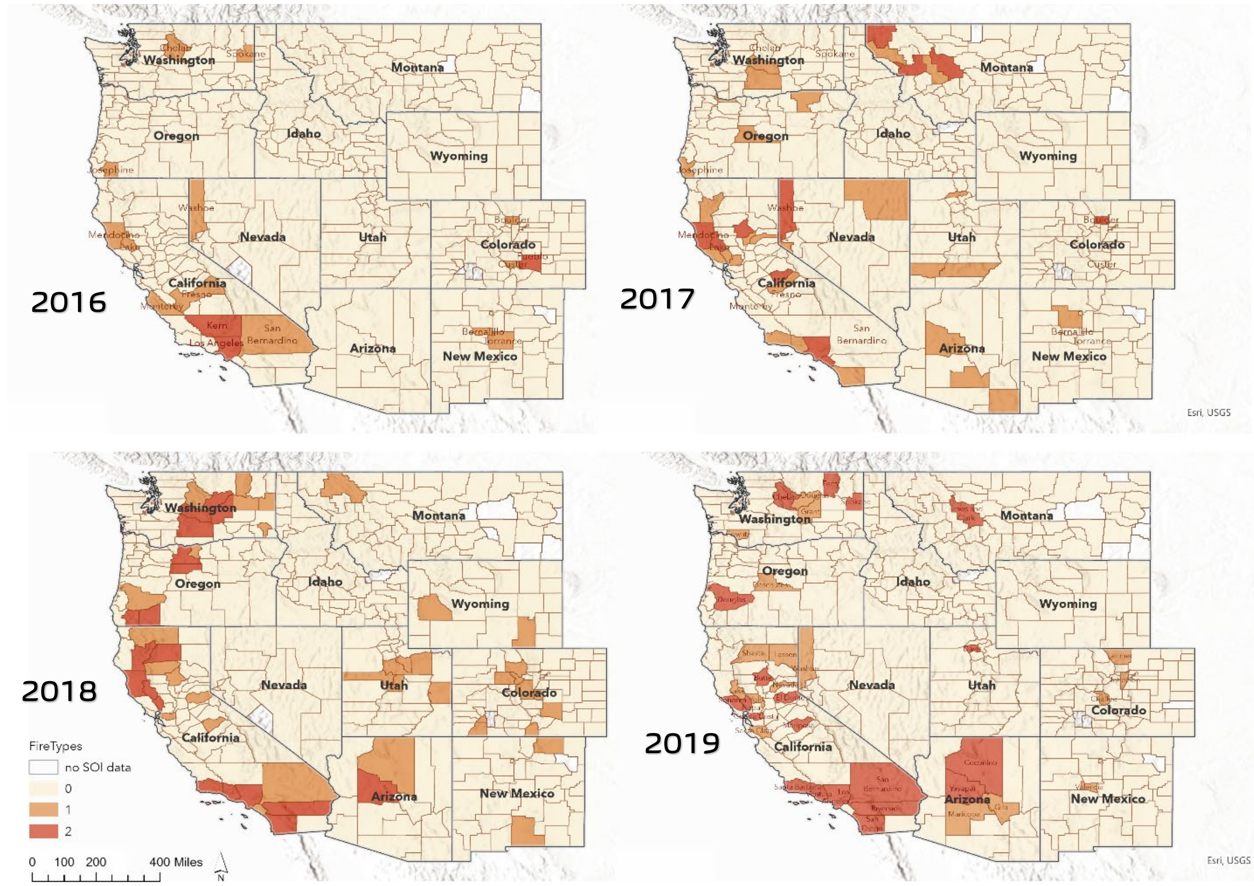


Figure 6. Spatial Distribution of counties within FireTypes treatment groups, by year

4.2 Migration Data

There are numerous data sources available for environmental mobility research with varying levels of complexity. Data sources range from traditional survey-based sources such as census data to novel big data sources including anonymous call record data (Sharygin, 2021, Table 3.3). The IRS Statistics of Income (SOI) program migration data was chosen for this study due to data accessibility during the study period and representation of full population of US taxpayers, rather than sampling. The IRS SOI program provides in-migration and out-migration estimates at the state and county level for the United States based on address changes reported on income tax return filings per year. For example, migration estimates for the year 2016 are reported as changes in residence listed at the start of tax year 2016 (year 1) versus start of tax year 2017 (year 2). In the SOI database, the number of tax returns is understood as a proxy for the number of households and number of exemptions (dependents) is used as a proxy for number of individuals (i.e. population).

SOI migration data at a county-to-county level is available for years 1991-2020. Out-migration estimates are provided as both origin county totals and destination county totals. Out migration estimates are provided for all counties with at least 20 returns (i.e. 20 households), records are removed for counties with less than 20 returns and marked with “-1” in the .cvs format (IRS SOI Migration Data Users Guide and Record Layouts, 2020). SOI data also includes aggregated gross income (AGI), reported in thousands of dollars, for all migrants at the county level, providing a rough estimate of migrant income trends.

This study uses the origin county totals for all domestic and international moves (“US and foreign”) provided within the SOI database as the measure of all annual out-migration per county. Out migration county-to-county data was downloaded for the 2015-2020 period in a .csv format then wrangled and joined to the wildfire time-series dataset in R. To calculate the household out migration rate (prHHmig), a count of total household records per county was calculated first by summing the count of all out migration (“County Total Migration - US and Foreign”) which includes all domestic (including domestic in-state or out of state) and international moves, with the count of all non-migrants (“County Non-migrants”).

Total Households per County = “County Total Migration - US and Foreign” + “County Non-migrants”

Within the SOI database, “non-migrants” are defined as tax returns for which the filer’s state and county of origin (year 1) matches that of their destination (in year 2). Thus, the non-migrant group represents tax filers who did not move or moved locally within the year (IRS SOI Migration Data Users Guide and Record Layouts, 2020). The household out migration rate was then calculated as households out migrating as percentage of total households per county.

$$\text{Household Out Migration Rate} = \frac{\text{“County Total Migration - US and Foreign”}}{\text{“Total Households per County”}}$$

Within the study period, 39 county-years were found to have missing records for out-migration (“-1”), representing out-migration totals of less than 20 households, and were ultimately dropped from the study.

Two limitations of measuring migration using IRS data must be mentioned. Both limitations center around the SOI’s differentiation between out-migration and non-migrant tax returns, which results in local moves (within same county) being excluded from migration estimates. For example, if a displaced person or household undertakes a local, post-fire move, staying within the same state and county of origin, they would be recorded as non-migrants and not captured within migration estimates used in this study. Recent wildfire migration findings showing a predominance of local post-fire moves (Jia et al., 2020; Sharygin, 2021) suggests that overall mobility outcomes related to wildfire hazard events are likely underrepresented across the SOI data. However, to some extent this is to be expected when working at a larger spatial resolution, such as the county scale.

Secondly, tax data may underrepresent the very poor and elderly populations who are less likely to file tax returns or be dependents (Gross, 1999). As repeated displacement from natural hazards can precipitate temporary or permanent homelessness for some individuals and households (Cowal et al., 2023), both data limitations together may alter the observable relationship between wildfire displacement and mobility patterns for existing high-vulnerability populations. Individuals experiencing extended displacement (i.e. homelessness) may file income taxes using a temporary mailing address such as local shelter or community service provider, and therefore would be captured as non-migrants within the SOI reporting format. While this study is focused on the relationship between wildfire event incidence and permanent relocation (i.e. wildfire-related migration), the blind spot within current analytical approaches to studying the relationship between hazard-related displacement and mobility remains a curious issue for researchers interested in a building a broader awareness of how climate hazards may alter local settlement patterns and community demographic shifts.

4.3 County Demographic Data

County-level data on socioeconomic demographics and development character was collected to prepare a series of competing independent variables for multivariate regression and to explore demographic trends. Competing independent variables were identified for inclusion in the study based on review of wildfire-specific and traditional migration literature. Variables representing greater economic resources for migrating, high mobility age groups, retiree age groups, metropolitan influence, and, conversely, poverty rate as a measure of existing low immobility groups were prepared within the dataset.

Age was controlled for using a young, high mobility age group (Millington, 2000) defined within the years 18 to 34. Additionally, as recent wildfire migration research found older groups displayed more post-fire migration (McConnell et al., 2021), a variable representing percent of county population over 65 (PrAge65Ov) was prepared. As economic resources have historically been linked with greater mobility (Van Hear, 2014), median household income was included for modeling. In contrast, homeownership has typically been related to lower migration rates based on the transactional costs of selling and moving or as a tie to location-specific capital (Leuvensteijn and Koning, 2000, Helderman et al., 2006). However, it is yet unclear how homeownership affects migration in the context of climate migration within a developed country. In some conditions, homeownership may also represent economic resources for mobility capacity (Rodriguez, 2021). With these considerations in mind, percent of owner-occupied housing units was included in the study to test home ownership's effect. Based on the theory of trapped populations where climate change stressors and natural disasters can exacerbate underlying vulnerabilities resulting in lower migration capacity (Black et a., 2011), poverty rates were included to evaluate potential dampening effects. Poverty rate was calculated as population living below the federal poverty line as percentage of total county population.

County data on population by age, household income, and poverty rate was acquired from the American Community Survey for year 2016 marking the beginning of the fire period, via the Census website (ACS, 2016). In reference to recent findings of disparate changes in migration rates between metro and non-metro areas related to natural amenities and wildfire incidence (Winkler and Rouleau, 2020), metropolitan status was controlled for using data from the USDA Urban to Rural Continuum Codes (USDA ERA, 2020). Together this county level data was cleaned and joined to the wildfire and migration time series dataset using combined state and county FIPS codes. The table on the following page provides a full list of prepared explanatory variables with supporting citations and data sources.

Table 6. County Socioeconomic Explanatory Variables

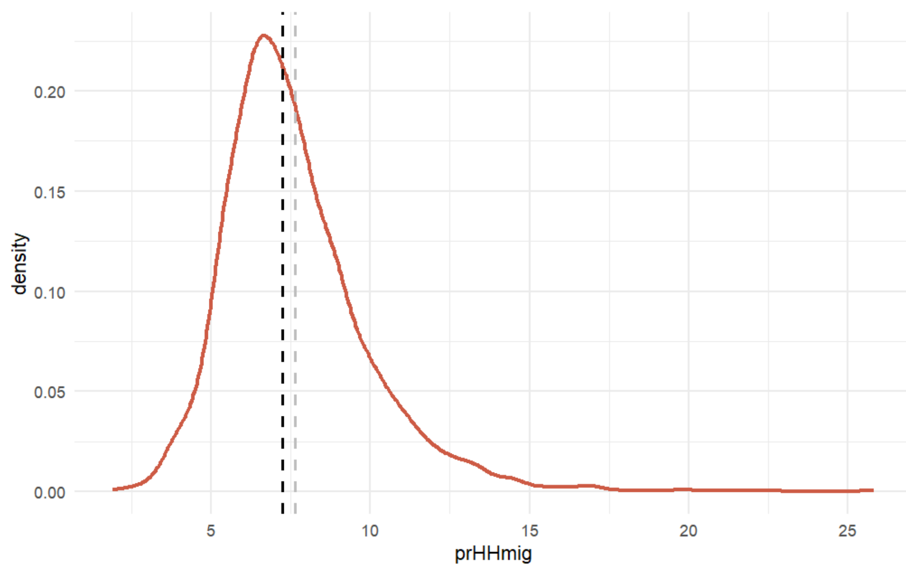
CODE	VARIABLE	DESCRIPTION	CITATION	DATA SOURCE
TOTHHMEDINC	Average (Median) Household Income	Measure of economic resources for relocating	Van Hear, 2014;	American Community Survey, 5-yr estimate 2016
PRAGE65OV	Percent of Population Over Age 65	Findings over 65 age group more mobile post-fire	McConnell et al., 2021	American Community Survey, 5-yr estimate 2016
PRPOP_18TO34	Percent of Population Ages 18-34	High mobility age group	Smith and Sage, 2014: Millington, 2000	American Community Survey, 5-yr estimate 2016
METROCODE	County Metropolitan Designation	Development character of county, metro influence	Winkler and Rouleau, 2020	Rural-Urban Continuum Codes, USDA ERA, 2013 (updated 2020)
PRHOUS_OWNOCC	Percent Owner Occupied Housing Units	Related to lowered out-migration rates, dampening effect	Winkler and Rouleau, 2020; Leuvensteijn and Koning, 2000; Helderman et al., 2006	Demographic Characteristics for Occupied Housing Units (ACS 5-yr estimate, 2016)
POVRATE	Percent of population living below poverty line	Measure of low economic resources for relocating	Black et al., 2011	American Community Survey, 5-yr estimate 2016

CHAPTER 5. RESULTS

5.1 Descriptive Statistics

Once the panel data was compiled, descriptive statistics of exploratory variables were prepared to explore the dataset. First, distribution of the dependent variable household out-migration rate was plotted, revealing a slight right skew indicating median to be the appropriate measure of central tendency for descriptive statistics (Figure 7).

Figure 7. Distribution of Household Out-Migration Rate for all Western Counties, For Tax years 2016-2019



(Data Source: IRS SOI, 2016-2019)

Caption: Black line represents the median and grey line represent mean.

Maps of the spatial distribution of counties and county-years within the fire dummy variables are provided on pages 41-44. Bar plots of median household out migration rates per FireTreat treatment groups found county-years with fire to have on average 0.47% lower out-migration rates than county-years without fire. Median out-migration rates for the FireTypes variable treatment groups show little difference (0.10%) between county-years without fire and county-years with only one fire (and no fire in the previous year). However, county-years experiencing repeated wildfire events (multiple annual or consecutive for back-to-backs years) are found to have on average 1% less out-migration than county-years without fire.

Next, descriptive statistics of prepared socioeconomic demographic variables were produced for the fire dummy variable treatment groups. As metropolitan and rural areas are known to have different migration systems, median out migration rates were compared between urban and rural counties within the dataset (Table 7). Typically, metropolitan areas, as cultural and economic centers with diverse labor markets, have dynamic migration systems with higher turnover, i.e., higher rates of both in and out migration (Millington, 2000). This difference was found to be muted with the prepared dataset, showing a difference of only 0.15% greater out-migration in metropolitan counties. This low difference may be due to the focus on western counties, where research has documented a well-established amenity-driven migration to rural areas as migrants seek environmental amenities in exurban and rural landscapes and tourism-based job markets (Winkler and Rouleau, 2020).

Table 7. Median Household Out-Migration Rate by Metropolitan Status

MetroCode	Household Out Migration Rate
Nonmetro	7.18%
Metro	7.33%

Data Source: IRS SOI, 2016-2019; USDA, 2020

Table 8. Metropolitan status by FireTreat

FireTreat	Metro	% Metro	Non-metro	% Non-metro	Total n of group
no fire	457	31.07%	1014	68.93%	1471
fire	87	59.59%	46	40.41%	146

Data Source: IDMC, 2020; USDA, 2020

Table 9. Metropolitan status by FireTypes

FireTreat	Metro	% Metro	Non-metro	% Non-metro	Total n of group
No fire	457	31.07%	1014	68.93%	1471
One fire	50	53.76%	43	46.24%	93
Repeat fire	37	69.81%	16	30.19%	53

Data Source: IDMC, 2020; USDA, 2020

Despite the small difference in migration rates between metropolitan and non-metropolitan counties, descriptive statistics of the metropolitan status (MetroCode) were created to determine if underlying trends exist within the treatment groups. Within the FireTreat variable, the no fire group includes approximately 40% more rural counties, while the fire treatment group is comprised of 20% more metropolitan counties (Table 8). Within the FireTypes dummy variable, counties experiencing one fire occur evenly between metropolitan and non- metropolitan counties (Table 9). Counties experiencing repeated fires are 30% more often in metropolitan areas within this time period.

Tables of median values of all numeric explanatory variables were also prepared by fire treatment groups (Table 10 and Table 11 on the following page). For the FireTreat groups, total population count and percent owner occupied are the most divergent variables, with fire treatment county-years showing much larger populations on average and 5% less homeownership rate. The age demographics showed low to moderate difference between FireTreat groups, with 1.29% greater percent young mobility group and 1.31% less percent population over age 65 found within fire county-years.

Table 10: Median Values of Explanatory Variables by FireTreat

FireTreat	n	Total Pop	HH Income	% Age 18-24	% Age Over 65	% Owner Occupied	Poverty Rate
No fire	1471	21,862	$47,241	20.31%	17.07%	69.36%	15.26%
Fire	146	110,238	$51,106	21.6%	15.76%	64.37%	16.14%
difference		*88,376*	*$3,865*	*1.29%*	*1.31%*	*4.99%*	*0.88%*

Data Source: IDMC, 2020; ACS, 2016

Table 11: Median Values of Explanatory Variables by FireTypes

FireTypes	n	Total Pop	HH Income	% Age 18-34	% Age Over 65	% Owner Occupied	Poverty Rate
No fire	1471	21,862	$47,241	20.31%	17.08%	69.36%	15.26%
One fire	93	84,063	51,106	21.17%	15.73%	65.81%	15.60%
Repeat Fire	53	210,916	51,106	22.01%	16.15%	62.65%	16.46%
Difference One fire vs No fire		+62,201	+$3,865	+0.86%	-1.35%	-3.55%	+0.34%
Difference Repeat fire vs No fire		+189,054	+$3,865	+1.70%	-0.93%	-6.71%	+1.20%

Data Source: IDMC, 2020; ACS, 2016

The population trend for fire treatment groups is repeated within the FireTypes variable grouping. Counties experiencing one fire event have higher population than counties without wildfire event and counties experiencing repeated wildfire incidences have the highest population. The percent owner occupied variable also continues to show a strong difference between treatment groups, with county-years with one fire having on average 3.5% less homeownership than no fire county-years and a 6.7% less homeownership for county-years within the repeated fire group as compared to no fire areas. Median household income is relatively consistent across the three groups. Overall, the repeated fire group tends to have a larger percent of young, high mobility age population, higher poverty rate, notably lower percent owner occupied rate, and much larger population than the no fire group. These qualities are often linked to urban areas (e.g. larger population, attractive to young workforce, more renters, and diverse socioeconomics).

5.2 Pooled OLS Regression Modeling

The plm package developed for running linear models on panel datasets was used in R to perform pooled OLS regression models. The model type was chosen as the first modeling approach utilized, with the understanding that additional modeling approaches are likely necessary to further evaluate model fit and provide testing for potential spatial and time effects within the data. Modeling was first run on the FireTreat dummy variable to test the statistical significance of household migration rates between county-years that experienced any wildfire displacement events versus county-years that did not experience wildfire events (Table 12). As the dummy variable is coded in a binary (0 or 1), the no fire treatment group (FireTreat 0) was dropped, making the no fire group the reference level for the model.

Table 12. Pooled OLS Regression Model: Household Out-Migration Rate ~ FireTreat

Code	**Variable**	**Coefficient**	**StdError**	**t-value**	**p-value**
FireTreat, No fire	Intercept	7.6927	0.0601	127.9953	p<0.00 ***
FireTreat, Fire	Fire	-0.5748	0.2000	-2.8741	p=0.004 **
R-squared	0.0051				
Adj. R-squared	0.0044				
F-statistic	8.2602 on 1 and 1615 DF, p-value = 0.004 **				
Total Sum of Squares	8625.4				
Residual Sum of Squares	8581.5				
Residuals	Min	1Q	Median	3Q	Max
	-5.7713	-1.5024	-0.4030	1.0505	18.1317

Unbalanced Panel: n=410 (counties), T = 1-4, N =1617 (county-year observations)

FireTreat model coefficient estimates indicate an expected 0.57% decrease in household out-migration rate for county-years with wildfire displacement events versus county-years without wildfire, at a significance level of p=0.005. However, the low r-squared values suggest that the model has questionable explanatory power. While adjusted r-squared values are generally lower for panel datasets, with an acceptable range of 0.20-0.60, the r-squared for the model is a low value of 0.005. In contrast, the

F-statistic, which is a measure of how jointly significant included explanatory variables are, has a p-value of 0.00 suggesting that the modeled correlation between out-migration and wildfire treatment is statistically significant. Overall, these results imply an opportunity to build greater complexity and explanatory power into the model through multivariate combinations.

With the primary goal of modeling the relationship between repeated wildfire event incidence and out-migration rates, the analysis continued to multivariate regression of the FireTypes dummy variable. Prepared explanatory variables were tested in various configurations against household out migration rates. The strength and fit of model combinations was determined through interpretation of p and r-squared values. During preliminary modeling, tests were also run to detect collinearity between prepared variables in effort to reduce overfitting of the model. Multi-collinearity is the condition in which underlying correlation between multiple independent variables can lead to skewed results and difficult interpretation within regression analysis. Two methods were used to determine the amount of collinearity between variables. First, a correlation matrix of all numeric variables was prepared, where correlation values range from 0 to 1 (Table 13) to show strength of relationship. The matrix format visualizes the relationship between two variables at a time.

Table 13. Correlation Matrix, Numeric Competing Explanatory Variables

	PrAge65Ov	**PrPop_18to34**	**TotHH_MedInc**	**PovRate**	**PrOwnOcc**
PrAge65Ov	1.00	-0.73	-0.43	0.02	0.41
PrPop_18to34	-0.73	1.00	0.13	0.25	-0.66
TotHH_MedInc	-0.43	0.13	1.00	-0.69	-0.07
PovRate	0.02	0.25	-0.69	1.00	-0.24
PrOwnOcc	0.41	-0.66	-0.07	-0.24	1.00

n=1617

Table 14. VIF Values, All Variables

	GVIF	Df
FireTypes	1.062	2
MetroCode	1.313	1
PrAge65Ov	2.916	1
PrPop_18to34	3.478	1
TotHH_MedInc	3.222	1
PovRate	2.605	1
PrOwnOcc	1.930	1

n=1617

Correlation matrix results (Table 13) indicate significant relationship between the young mobility and over 65 group variables (0.73) as well as a notable amount of correlation between income and poverty variables (0.69). To cross-reference these findings, the Variance Inflation Factor (VIF) was also used to test for multi-collinearity (Table 14). As a rule of thumb, VIF values equaling 1 indicate no correlation between variables, while values between 1 to 5 indicate moderate correlation, and VIF values greater than 5 suggest a high level of correlation between explanatory variables. VIF test of the variables prepared for this study again revealed moderate correlation in relation to other variables for the young mobility group (PrPop_18to34, GVIF = 3.478), median household income (TotHH_MedInc, GVIF = 3.222), and the retiree group (PrAge65Ov, GVIF = 2.916. To a lesser extent, the poverty rate (PovRate, GVIF = 2.605) displayed low to moderate correlation with other variables within the set. The decision to limit competing explanatory variables in final models was made based on these correlation estimates and in effort to avoid over complexity in a model with limited observations (repeat fire group, n = 53 county-years).

Variables were ultimately grouped for final models to minimize collinearity, improve strength, and in effort to observe potential facilitating or moderating patterns on migration rates. The lower average out migration rates for counties experiencing repeated fire events versus counties without fire indicated a need to control for measures of low mobility within county demographics. In accompaniment, variables associated with high mobility were modeled for comparison, to test if mobility facilitating effects accounted for more variation. With these goals, two final multivariate regression models were prepared, one including competing variables typically correlated with lower mobility (Table 15), and another with competing variables typically correlated with higher mobility (Table 16). The lower mobility model includes non-metropolitan counties (MetroCode), poverty rate (PovRate), and percent owner occupied housing units (PrOwnOcc). The higher mobility model includes total county population (T_Pop), young high mobility group (i.e. ages 18 to 34) (PrPop_18to34), and median household income (TotHH_MedInc). As metropolitan status was not seen to have strong relationship to increased out-migration rates during preliminary modeling, total population was substituted to test for urban population influence within the high mobility model. In both the low and high mobility multivariate models, the no fire treatment group was dropped to act as the reference level within the model.

Results of the low-mobility model of FireTypes show a statistically significant, expected 1.45% decrease in out-migration rate for county-years experiencing repeated wildfire displacement events (Table 15). Conversely, the one fire group, representing county-years experiencing only one fire, is found to be statistically insignificant. All included competing variables are shown to have statistically significant dampening effects on out-migration rates, though to lesser extents than repeated wildfire event incidence. County poverty rate is shown to have the second biggest effect on out-migration rates after repeated wildfire event incidence, relating to a 0.08% decrease in out-migration rates at a high significance level of $p<0.000$.

Table 15. Pooled Multivariate OLS Model:
Household Out-Migration Rate ~ FireTypes + Low Mobility Explanatory Variables

Code	**Variable**	**Coefficient**	**StdError**	**t-value**	**p-value**
FireTypes 0	Intercept	11.2340	0.5613	20.0138	p<0.000 ***
FireTypes 1	One fire	-0.2944	0.2386	-1.2343	P=0.2172
FireTypes 2	Multi fire	-1.4470	0.3149	-4.5950	p<0.000 ***
MetroCode	Nonmetro	-0.0505	0.0102	-4.9379	p<0.000 ***
PrOwnOcc	Percent Owner Occupied Housing	-0.0184	0.0079	-2.3123	p=0.021 *
PovRate	Poverty Rate	-0.0837	0.0111	-7.5334	p<0.000 ***
R-squared	0.0763				
Adj. R-squared	0.0735				
F-statistic	26.6287 on 5 and 1611 DF, p-value < 0.00 ***				
Total Sum of Squares	8625.4				
Residual Sum of Squares	7966.9				
Residuals	Min	1Q	Median	3Q	Max
	-5.5832	-1.4561	-0.3268	1.1258	17.647

Unbalanced Panel: n=410 (counties), T = 1-4, N =1617 (county-year observations)

Table 16. Pooled Multivariate OLS Model:
Household Out-Migration Rate ~ FireTypes + High Mobility Explanatory Variables

Code	**Variable**	**Coefficient**	**StdError**	**t-value**	**p-value**
FireTypes 0	Intercept	2.7954	0.2782	10.0485	p<0.000 ***
FireTypes 1	One fire	-0.3523	0.2243	-1.5707	P=0.116
FireTypes 2	Multi fire	-0.8418	0.3069	-2.7425	P=0.006 **
T_Pop	Total Population	-7.97e-07	8.78e-08	-9.0762	p<0.000 ***
PrPop_18to34	High Mobility Age Group	0.13238	0.0100	13.1882	p<0.000 ***
TotHH_MedInc	Median Household Income	4.56e-05	4.04e-06	11.2663	p<0.000 ***
R-squared	0.1863				
Adj. R-squared	0.1838				
F-statistic	73.7783 on 5 and 1611 DF, p-value < 0.00 ***				
Total Sum of Squares	8625.4				
Residual Sum of Squares	7018.3				
Residuals	Min	1Q	Median	3Q	Max
	-5.0104	-1.4165	-0.2732	1.0843	15.2804

Unbalanced Panel: n=410 (counties), T = 1-4, N =1617 (county-year observations)

County non-metropolitan status is associated with a 0.05% decrease on out-migration rates, with high significance at p<0.000. Percent owner occupied housing is related to a 0.02% decrease in out-migration rates, at a lower significance level of p<0.05. The low mobility model has a r-squared value of 0.0763 and adjusted r-squared of 0.0735. These r-squared values are rather low and may suggest unaccounted for variance and room for improvement in the model, whether by exploring other influences on migration rates (other explanatory variables) or utilizing different modeling techniques. However, the F-statistic indicates that the explanatory power of the model with these combined explanatory variables is highly statistically significant at p<0.000 showing a support for model strength.

Results of the high-mobility model of FireTypes followed a similar pattern for the dummy variable treatment groups, though with an appreciably greater effect for the repeated fire group. The incidence of repeated wildfire displacement events is linked to a statistically significant, 1.95% decrease in out-migration rates as compared to the no fire group (difference in coefficients). The one wildfire group again showed a smaller 0.39% decrease on out-migration rates but was not found to be statistically significant. All included explanatory variables were shown to be highly statistically significant, though imparting a smaller effect on out-migration rate variation than the repeated fire treatment group. Within the competing variables, young mobility age group had the largest effect with a 0.13% increase in out-migration rates, with p value less than 0.00. Median household income had a 0.0000456% effect or, when presenting the effect based on the dollar unit of measurement, a 0.045% increase in out-migration for every $1,000 increase in household income or 0.46% increase for every $10,000 increase in household income. Surprisingly greater county population was shown to be related to a decrease in out-migration rates, of approximately 0.0008% for every 1,000 persons or

0.008% for every 10,000 persons. Both effects for median household income and total county population showed statistical significance with p values less than 0.00. The adjusted r-squared for the model is 0.1838 suggesting the high mobility model is a better fit and explains more variation in the dependent variable than the low mobility model. This adjusted r-square is quite close to the acceptable range for panel data which is 0.20-0.60. The F-statistic also indicates significance of the high mobility model with a p value less than 0.00. The results are particularly interesting as the high mobility model shows a higher effect for repeated fire on out-migration rates.

CHAPTER 6. DISCUSSION

6.1 Discussion of Findings

Overall model results indicate that the incidence of repeated wildfire displacement events has a statistically significant effect of decreasing household out-migration rates by approximately 1.5-2%. None of the competing explanatory variables relating to typically higher mobility or low mobility capacity negated the statistical significance or showed greater effect than that of repeated wildfire impacts on out-migration rates. Conversely, the one fire group was found to have no statistical significance, therefore results show no meaningful difference between no fire and one fire county-years within the dataset. This dampening effect found for repeated wildfire displacement incidence is a somewhat surprising result that warrants further consideration and testing. These findings differ from those of recent wildfire migration research, which found heightened rates of out-migration for FEMA designated disaster-level wildfires (Winkler and Rouleau, 2020) and 0.07% greater out-migration for the top 5% most destructive recent wildfires (McConnel et al., 2021).

A major consideration at the outset of this study was the potential impact of post-disaster relief funding for homeowners, which can support recovery in place and thus facilitate immobility outcomes (Winkler and Rouleau, 2020). The relatively small effect and lower statistical significance of percent owner occupied housing within modeling may indicate that financial support for homeowner recovery does not effectively explain the low migration rates found in this study. If we hypothesize that disaster recovery funding may alleviate migration pressure and thus dampen wildfire-related out-migration, then we might expect to see no difference between the repeated fire group and no fire group, i.e. a return to baseline migration rate. However, the results of this study do not show a return to baseline. Instead, we see less out-migration in repeated fire county-years than no fire county-years. Thus, the concern that an underlying relationship between wildfire evacuations and wildfire disaster events may result in a dampening of observable out-migration is unsupported or unclear based on model results. However, the brevity of the study period, only 4 years, and research design limit observation of such a return to baseline. Limitations due to time or unaccounted for influences within modeling are discussed further in the following 'Limitations' section.

If we hypothesize that metropolitan areas with greater population and development density thus representing greater vulnerability to wildfire damages may receive substantial recovery funding, then we may expect metropolitan influence to be significant in a model showing dampened out-migration rates. This is not found to be the case. As the group of counties experiencing repeated wildfire events is composed of a greater number of metropolitan counties than nonmetro, this is an especially relevant consideration. However, findings related to the county total population variable show a very small dampening effect on out-migration rates for larger, urban populations. This is another surprising result that warrants further investigation, especially of spatial effects not captured within the OLS model. See the limitations section below for elaboration. Overall, the non-significance of county metropolitan status suggests that the use of evacuation data for this study did not skew the data via metropolitan influence.

Instead, the relative size and high significance of the poverty rate's effect on out-migration, in comparison to other variable effects, displayed in the low mobility model may support the theorization that repeated exposure to wildfire displacement events may lower migration capacity via negative impacts on household economic resources (Schewel, 2019) within the context of the western US. Conversely, lowered migration desire could account for lower out-migration rates in repeated fire county-years. While

Winkler and Rouleau found sharp increases in out-migration for counties with disaster-level wildfires, counties experiencing both fire and neighboring fire showed decreased in migration and no difference in out-migration. The authors reasoned this low effect may be due to residents' reduced prospect for relocation, as most moves are local or intraregional (Winkler and Rouleau, 2020). It could be reasoned that repeated exposure to potential wildfire displacement may also limit relocation prospects.

As stated, percent homeownership is shown to have less impact on out-migration rates in this study than expected based on previous literature. While these results uphold the dampening effect of home ownership as seen in general migration studies for the context of wildfire migration, the small magnitude of these result may also lend some support to recent speculations that home ownership may play a different role with respect to migration potential in the context of climate change in the US. These findings differ from those of Winkler and Rouleau, who found a strong relationship between homeownership and immobility. However, their findings may have been influenced by limiting the study to only disaster-level wildfires which by FEMA designation triggers federal recovery assistance that may require homeowners to rebuild in place. Findings related to owner occupancy rate within this thesis may also be considered in hand with the strong relationship observed between household income and increased out-migration. While this study did not test the relationship of wildfire exposure and migration when disaggregating households by income brackets, the stronger r-squared and high significance (F-statistic p value less than 0.00) for the high mobility model when including household income suggest the importance of economic access to migration in the context of wildfire. This would agree with McConnell et al., who found high-credit score groups were the most likely to migrate after destructive wildfires (McConnell et a., 2021).

6.2 Limitations

Apart from previously mentioned data constraints, a major limitation of this study is the length of the time-series. Migration and fire incidence are compared over a period of only 4 years. While additional years of SOI data are available, prior to 2014 there is limited to no location information provided for hazard events within the IDMC database available to perform spatial analysis. This challenge comes from working with a relatively new and novel data source for population-focused hazard impacts. Creating a long period of study may require revisiting the source of wildfire data.

As mentioned, wildfire data for the year 2020 was dropped from the dataset due to delays in IRS SOI data release for the 2020-2021 tax filing season. The considerable delay in data availability from government resources such as the IRS is a notable limitation for mobility research in general. It must also be noted that statistical findings based on historic, empirical data have inherent limitations with respect to predicting future conditions. The limitations of historic evidence when planning under climate uncertainty is a well-known issue within planning (Hallegatte, 2009). As climate change drives greater departure from previous conditions, such as increases in natural hazard incidence from prior decades, the need for more timely access and up-to-date information grows in importance. However, in the case of this study, the omission of 2020 data and beyond may have been of some benefit, in not introducing well-documented Covid-19 pandemic-related changes in US domestic migration rates and patterns into the dataset (Rogers, Perry, and Spell, 2023; Coven, Gupta, and Yao, 2023; Haslag and Weagley, 2022). In its current form, the dataset prepared in this study provides a snapshot of the most recent wildfire and migration figures unimpacted by the Covid-19 pandemic.

In relation to model strength, r-squared values may suggest unaccounted for variance in the data, especially within the low mobility model. One approach may be to improve the model by including additional explanatory variables. For example, one aspect of the wildfire problem that was not explored in model is the influence of wildland urban interface (WUI) development. Percent WUI per county or percent of population living within WUI areas per county may be tested within the model for effects. Summary statistics including percent of land area, percent of housing, and percent of population within the WUI per county are available from the University of Wisconsin Madison's SILVIS Lab. Additionally, the SILVIS lab provides WUI spatial data is raster format for all western states. Inclusion of a percentage of area or population within the WUI may also improve the model by incorporating more measures of spatial variance between counties. However, a WUI variable may not represent a competing cause of migration, but rather specification on where variance in wildfire-related migration is occurring within the western US.

There are also inherent limitations of only using an OLS linear regression model within the study. There is opportunity to pursuit additional modeling approaches to test for spatial and temporal variation within the data. For example, some clustering of wildfire events in the state of California, especially for the repeated wildfire treatment group, may be of particular concern. Statistics from the National Interagency Fire Center show California leads the country in number of wildfires, acres burned, and size of population with wildfire risk (Insurance Information Institute, 2023; NIFC, 2021). Incorporating some measure of disaster-level wildfire events within the data may help better determine the source of variation and/or dampening out out-migration rates association with repeated fire counties. Data from the Federal Emergency Management Agency (FEMA) or data tracking prevalence of wildfire housing destruction per state is also available from the SILVIS lab may be potential sources for this information.

Despite these limitations, the methodology of pairing migration measures, hazard incidence, and regional demographics developed within this study may be adapted to other climate stressor or natural hazards within the US. Variation in terms of regional development character and associated risk, demographics of vulnerable populations expressed in terms of underlying socioeconomic conditions, and existing migration networks must all be considered when adapting this format to other climate hazard types. As mentioned, the availability of data on climate change impacts, especially for slow-onset climate stressors, will likely create limitation to adaptation of this study's methodology. As such, this work supports the need for greater data tracking and accessibility on climate change impacts whether large and disastrous or mundane and incremental.

6.3 Conclusion

This study seeks to contribute to the literature on US domestic climate migration, specifically for an audience of planners whether working on national, regional, or local scales. Due in part to the complexity of climate migration and the nascent stage of its study within the context of developed countries, it is unclear how climate stressors may impact existing domestic migration patterns within the US. Economic structures such as insurance, federal disaster recovery funding, and municipal adaptation efforts may alleviate stress and dampen migration pressure (Kousky, 2021). However, existing resource disparities within the US population and inequitable access to relief funding must also be taken into consideration (Davies et al., 2018).

Within the context of planning, climate migration research such as developed by this study is intended to help planners build capacity within climate change adaptation strategies and policy to accommodate shifting populations. If climate change does intensify or alter existing migration trends, planners may need to re-evaluate infrastructure needs whether in terms of housing, transit, and utility capacities. To create effective public policy, planners will need to gain a better understanding of who climate migrants may be and where they are moving, as well as answer questions around populations potentially constrained by immobility and heightened hazard risks. Therefore, broadly, an additional goal of this study was to build an accessible methodology that can facilitate interregional information sharing and provide planners with an outlook unrestrained by their typical administrative jurisdictions.

Model results reveal statistically significant relationships between most explanatory variables including the incidence of repeated wildfire displacement events. Results suggest that repeated incidence of wildfire displacement has a dampening effect on existing household out-migration rates. On average county-years experiencing repeated wildfire, whether occurring consecutively year after year or as multiple fires within the same year, were more often metropolitan than rural. These findings may demonstrate that the concept of trapped populations (Black et a., 2011, Hunter, 2005) may have merit within the context of repeated sudden onset stressors occurring in urban areas of the US.

It is important to note that this study limited its view to out-migration rates, without comparison to in-migration, i.e. net migration rates. The findings herein do not equate to decreased net migration in counties experiencing repeated wildfire displacement events. To the contrary, recent census data reveals overall net population gain for most western states, especially in the high-arid and fire prone desert southwest region (Mackun, 2019). Likewise, recent analysis of real estate data indicates that disaster-prone counties saw an average of 4.7% population growth due to positive net migration during 2016-2020 (Katz and Sandoval-Olascoaga, 2021).

California is an exception to this trend, with recent population losses noted in major metropolitan areas such as Los Angeles, Santa Clara, and Alameda counties (Bloremraad and Roubenoff, 2023). While some researchers align California's recent increases in out-migration with broader pandemic era trends that fall outside of this study's period of inquiry, others point to a decade long increase in out-migration rates (Johnson and McGhee, 2023). As many repeated fire county-years examined within this study fell within California, these state specific trends are relevant to interpretation of results. Recent increases in out-migration rates for California would then imply by comparison that the lowered out-migration rates for repeated fire county-years is an especially strong indicator of dampened mobility.

While questions and limitations remain, the findings of this study are relevant to considerations of community disruption, displacement, and the larger conversation of how repeated hazards affect mobility within the western US. Potential evidence of immobility effects found within this study imply the need for continued research to build greater understanding of how climate hazards may exacerbate existing vulnerabilities in high-risk locales and render adaptive migration unequally accessible.

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