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Population recovery in U.S. communities affected by tornadoes, 2000–2010

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Abstract
We investigated the demographic changes in American communities impacted by tornadoes from 2000 to 2010, exploring the factors influencing population recovery in tornado-affected communities, considering short-term (within one year) and long-term (2–10 years) outcomes. Using logistic regression models, we analyzed seven predictor variables to identify significant contributors to population recovery, including tornado strength, community size, population trend, and state status (Sunbelt or Snowbelt). The data encompassed 516 tornado-affected communities across the conterminous United States. Our findings revealed that about 55% of the communities experienced no significant population change immediately after the tornado event. However, 44% of the communities witnessed a population decline, and only 11% fully recovered within 2–10 years. Results indicated that community size and trends were pivotal in population recovery. Communities with negative population trends, especially those with fewer than 5,000 residents, faced significant challenges regaining their pre-tornado population size within 1 year. The data did not show a significant difference in population recovery between communities in the Sunbelt and Snowbelt regions. The study highlights the importance of community-level factors in shaping population recovery dynamics following tornado events. Understanding these factors can aid community leaders and disaster managers in formulating effective strategies to retain populations and encourage rapid recovery. Although certain limitations exist due to data availability, future researchers could explore additional factors, such as post-tornado policies and socioeconomic variables, to gain comprehensive insights into post-disaster population dynamics. Our research contributes value to social science disaster research, helping communities build resilience in the face of tornado hazards.

Keywords Tornadoes · Population · Tornado recovery

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1 Introduction

Tornadoes can produce various demographic changes in affected communities. For some communities, the post-disaster total population never reaches or takes some years to attain the pre-event level—primarily caused by some disaster survivors resettling nearby or distant unaffected communities. People move out of affected communities because of many factors: (a) limited access to employment opportunities, particularly in small communities; (b) lack of safety and security provisions in the aftermath of the disaster; (c) non-availability of housing or increased housing costs; and (d) previous migration experience (Fothergill and Peek 2004; Haney 2018; International Organization for Migration, 2008; Pais and Elliot 2008). The movement also depends on the imposition of new land use regulations, building codes, construction practices, and other programs, such as new development restrictions by emergency managers and local government entities of disaster-affected communities (Lindell and Prater 2003; Paul and Stimers 2015; Tierney et al. 2001).

Some disaster-affected communities show no effect on the total population size. In such communities, the population continues to grow consistently immediately following the event and in subsequent years. Thus, communities experience net population gains or even an acceleration in total population growth (Pais and Elliot 2008; Raker 2020; Schultz and Elliott 2013). This differential response to disaster-affected communities has yet to be studied much by population or hazard researchers. To help fill this gap, we examined post-event changes in population size in American small and medium-sized towns and cities affected by tornadoes from 2000 to 2010. Specifically, we tested two models to identify the factors: (a) one model in which no population change occurred immediately after tornadoes struck them, and (b) a second model employed whether these communities recovered pre-tornado population within 2–10 years. This study makes crucial contributions to the social science disaster research literature by examining post-event population recovery in the context of tornado risk and vulnerability. Population dynamics, particularly population growth and migration, are among the most critical factors that have increased our exposure to disasters and their damage and loss of lives (Paul 2011, 2021).

2 Theoretical framework

A community's post-disaster population size depends mainly on the relocation decisions of surviving individuals and households.[1] Other considerations are post-tornado policies and programs for housing recovery and improving safety measures by the affected community leaders influencing these decisions. Empirical evidence suggests that some survivors leave the affected community immediately after the event (Brock & Paul, 2003; Cross 2001).

In this paper, we endeavored to understand the recovery of the population of communities in the United States struck by a tornado through the lens of the fear of severe weather, termed *lilapsophobia*, and other relevant theoretical frameworks in the hazards and disasters literature. Some researchers have considered fear adaptive (Buss and Larson 2000; Southwick and Charney 2018). For example, adaptive fear of tornadoes can help households be prepared by constructing safe rooms within their houses and storm cellars outside the house or seeking shelter in basements when household members need to. Although these safety

[1] Communities are loosely defined as small geographical units (e.g., neighborhoods, places, or towns).

measures reduce the risk of loss of life, injury, and property damage, as well as increase tornado resilience for households and communities, these measures require the financial abilities of the households.

Like lilapsophobia, the terror management theory (TMT) indicates that potential fear or anxiety of death motives some households to leave the disaster-prone community (Greenberg et al. 1997; Pyszczynski et al. 1999, 2003). Others reject their fear and traumatic experience by denying their vulnerability to threat, distorting its immediacy, and distracting themselves from it (Chaplin 2000; Pyszczynski et al. 2003). Generally, people who experienced a recent disaster assume that the event will not occur again in their communities for quite some time. Slovic et al. (1974) referred to this common misconception as the *gambler's fallacy* (Burton et al. 1993).

However, relevant leaders of disaster-affected communities can reduce the fear of weather-related hazards among their residents by introducing safety measures. This concept is known as the *window of opportunity* in the disaster literature (Birkmann et al. 2010; Davidsson 2020; Olshansky 2006). The immediate aftermath of a tornado or any other disaster provides the opportunity for local government and disaster managers of affected communities for disaster risk reduction (DRR) and improved redevelopment by enforcing and recommending new regulations to upgrade safety measures. These measures improve the quality of housing and, therefore, reduce potential loss of lives, injuries, and extent of destruction (Paul 2022; Prater & Lindell 2000). Depending on the cost of safety measures and available funds from outside, people of affected communities may be encouraged to stay in their residences.

Local government entities and active support from state and federal governments provide financial support to tornado survivors to rebuild their destroyed or damaged houses according to newly imposed and recommended building and land use codes. For communities in developing countries, donor countries and foreign agencies, such as the World Bank, the Asian Development Bank (ADB), and the United States Agency for International Development, often supplement domestic support (USAID; Paul 2022). Besides, other economic incentives, such as subsidies, low-interest loans for implementing new safety measures, or tax breaks by local government, reduce the out-migration of tornado survivors to surrounding communities. These incentive measures retain tornado survivors in an affected community and benefit the community because they do not reduce the local tax base (Cross 2001). Suspecting that survivors of the 4 May 2003 tornado might move to other places, leaders of the five tornado-impacted cities (Liberty, Pleasant Valley, Gladstone, and Northmoor in Missouri and Kansas City in Kansas within the Greater Kansas City Metropolitan Area) quickly announced special incentives to encourage resident rebuilding in their communities (Dvorak and Wiebe 2003).

Despite economic incentives, some residents of tornado-affected communities may either be leaving or thinking about moving to other towns or cities before the event (Smith and Cartlidge 2011). A tornado event helps them to speed up the process; this is particularly true for some elderly residents, who generally view the post-tornado as providing an opportunity to move away from the affected communities after receiving insurance money (Smith and Cartlidge 2011). If they live in isolated and rural communities in Snowbelt states (Balland and Rigby 2017), they generally prefer to move to communities in the Sunbelt (Jewell 2020) states. A sizable portion of the older population did not return to Greenburg, Kansas after an EF-5 tornado struck the southwestern Kansas town of 1,400 people in 2007 (Smith and Cartlidge 2011). Even by 2023, the city population had not reached the pre-tornado level.

For some people in their retirement years, the decision to rebuild houses after a tornado disaster is even more difficult. They must weigh the long-term financial costs and benefits and the availability of medical, assisted living, and church facilities in the affected communities. As long-time residents of the affected communities, they also have strong emotional connections to the communities, which acts as a barrier to rebuilding in a new location (Adams 2016; Smith and Cartlidge 2011). However, a window of opportunity also leads to out-migration from tornado-affected communities. For example, after experiencing an F4 tornado in 2001 in Hoisington City, Kansas, authorities enforced one land-use regulation, which restricted construction of damaged or destroyed homes on 50-foot-wide (15.24 m) lots in the tornado-affected northeastern community. Many people who wished to rebuild homes in the affected area had to purchase adjacent lots to satisfy the requirement. As a result, the housing density in the area became less than 50% of pre-tornado density and is much lower than in the non-affected areas of the city (Brock & Paul, 2003). Many people in the affected part of the city could not buy additional 50-foot lots to reconstruct their houses. Consequently, many did not return to the city, and the population declined. According to the U.S. 2020 population census, the city still needs to recover its pre-tornado population size after 20 years (United States Census Bureau 2021).

The frameworks and prior findings appear together to provide valuable concepts and powerful tools to understand the population recovery of communities affected by tornadoes. With the aid of these frameworks, we have selected the relevant determinants of whether a tornado-affected community recovers from pre-event population size. These determinants are separated broadly into four classes: (a) physical characteristics of tornadoes, (b) post-tornado policies of affected communities, (c) community characteristics, (d) and individual or household attributes. The present research shows only one critical physical characteristic of tornadoes (strength or magnitude). Magnitude as an attribute, coupled with factors aligned to vulnerability, triggers several threats and determines the extent of casualties among the population and the damage to structures in the affected community (Lindell and Prater 2003; Paul 2021). Other characteristics of tornadoes, such as duration, spatial extent, and width of the event path, are not considered because they vary little from one to another (Grazulis 1993; Simmons and Sutter 2011).

Pre- and post-tornado policies and programs, including financial incentives by the leaders of tornado-affected communities, are the second broad determinant, divided into two sub-types. The first sub-type includes community protection works (e.g., on-time issuing of a tornado watch, warning, and lead time), land use, and building construction practices (Donner 2007; Lindell and Perry 2000; Paul 2021). Community protection works to limit the impact of a hazard agent on the entire community and reduces weather-related fear among the residents. The second sub-type includes other supports and incentives the affected local government provided, as discussed above under the Window of Opportunities section.

The third broad category reflects community characteristics such as community size concerning population, population trend for the preceding census decades, and whether it is the county seat or a suburb of a larger city. If the affected community is relatively large or characterized by a positive population trend, the community population will tend to recover quickly (Cross 2001; Donner 2007). That is also true if the affected community is a county seat or a large city suburb. Community characteristics also include population composition (e.g., age, gender, percentage of African Americans, and percentage of manufactured homes) and economic conditions (e.g., poverty rate, median income, and percentage of manufactured homes). Finally, the fourth broad group of determinants is the individual and the household's decision to stay or not stay in the tornado-affected community. Many factors influence that decision, including (a) a lack of employment opportunities, (b) the cost of rebuilding, and (c) the intensity of the fear of tornadoes. Since the study unit was the community, these factors went unused here.

3 Data and methods

3.1 Selection of the study period and the Tornado-affected communities

The period we considered in this study included 2000–2010. Using the terminal year helped follow the population change of tornado-affected communities for at least 10 years, explaining why the base year does not extend through the 2020 census year. Based on Storm Prediction Center data (https://spc.noaa.gov/wcm/#data), Statista (2022) presented summary data in bar graph form and stated that 14,020 tornado events occurred in the United States during the study period. However, not all tornado events were selected. The study excluded 8,887 (63.39%) of those events either rated as F/EF-0 on the Fujita/Enhanced Fujita Scale or a category of unknown scale. However, most of these were in the former category, which had minimal impacts on affected communities (Simmons and Sutter 2011). Note that F/EF-0 tornadoes are the most common in the United States. As recommended by a few tornado researchers in the USA (e.g., Cross 2001; Pais and Elliot 2008; Simmons and Sutter 2011, 2012; Johnson 2022), we eliminated tornado-affected communities with a population of less than 500 and more than 100,000 because of several reasons. Their population growth potential is likely to be very small and large, respectively (Cross 2001; Simmons and Sutter 2011). Additionally, residents of smaller cities are often far more vulnerable to tornadoes than residents of larger cities (Paul 2022). The latter cities are often better prepared than the former cities. Also, tornadoes can affect the entire area of a smaller city, while the effect can be only on a small part of a larger city (Cross 2001; Simmons and Sutter 2012).[2] Tornado-affected communities within the conterminous United States were selected, but we excluded those without relevant population information. Thus, 516 tornado-affected communities were chosen in this study (Fig. 1).

The National Weather Service's (NWS) Strom Prediction Center (SPC) annually publishes each detected tornado event in the United States in two forms. The SPC published killer tornado data by communities from 2000 to 2007. The SPC also published tornado track data for the killer tornadoes since 2007 and non-killer tornadoes for the study period.[3] The latter data for 2000–2009 emerged from Stimers (2011; Stimers and Paul 2016). The SPC provided tornado data for 2010. We extracted the necessary community data from tornado tracks for each year in the study period using an initial base map from the National Atlas and shapefile data containing U.S. states, 3,116 counties, and 25,148 geographical units. The U.S. Geological Survey (USGS) has produced the National Map Viewer since

[2] The average area affected in the USA by a tornado is slightly over one square km (Simmons and Sutter 2011, 2012).

[3] A tornado event that kills at least one person is a killer tornado.

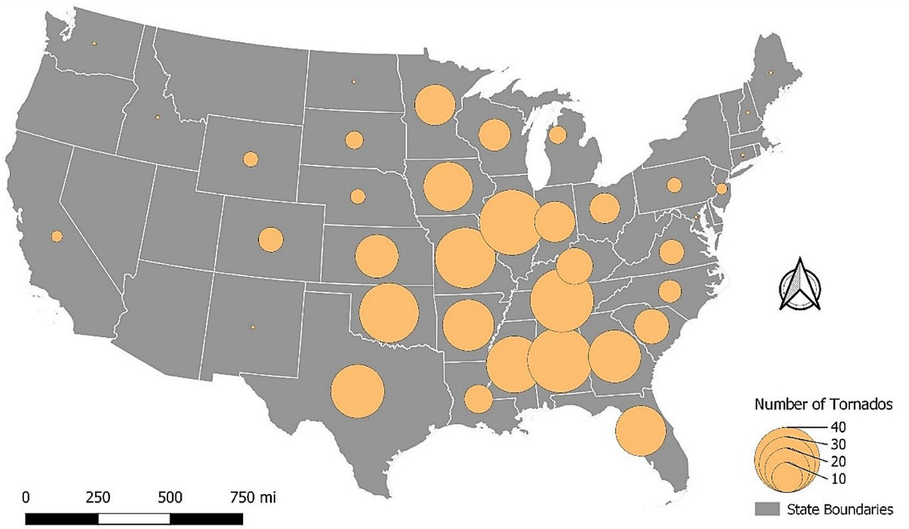

Fig. 1 Number of tornadoes (EF > 1) that affected U.S. communities (2000–2010)

2014. However, these map layers are called the states, county (or counties), and community (or communities) shapefiles. We imported those data into a geographic information system (GIS) program for analysis.

Point data containing the beginning and ending latitude and longitude of all tornado events (herein named points) as well as polyline data for all tornado tracks (herein named as tracks) from 2000 to 2009 derived through the SPC's GIS data portal (SPC, 2010). We imported the points and track shapefiles for all tornadoes during the study period into a GIS. This study considered only those tornadoes that passed through an American community.[4] Note that a tornado track may not pass through a community or may pass through more than one community (Fig. 2).[5] Generally, the tornado touches a part of a sizable community. If the size of the tornado-affected community is minimal, it may pass through the entire community. We followed the above procedures for communities affected by tornadoes in 2010 and killer tornadoes since 2008.

3.2 Selection of determinants

Based on the theoretical framework and our experience with tornado studies in the U.S. for more than 2 decades, we selected seven factors for each model as independent variables (Table 1). The two dependent variables of the study reflect population recovery to pre-tornado level, either within one 1 or 2 and up to 10 years after a tornado. The first independent variable is tornado strength (magnitude) or severity. It is a crucial physical dimension of the event, which generally influences the number of deaths and injuries—the distribution

[4] Not all tornado tracks in the U.S. intersect a community or pass-through population area (Simmons and Sutter 2011; Stimers 2011).

[5] Sometimes, a tornado does not strike even an entire small community. For example, an EF-5 struck Greenburg, KS, in May 2007; it destroyed 95% of this small town. Before the tornado, it had a population of nearly 1,500 with an area of 1.79 square miles (Paul and Che 2011).

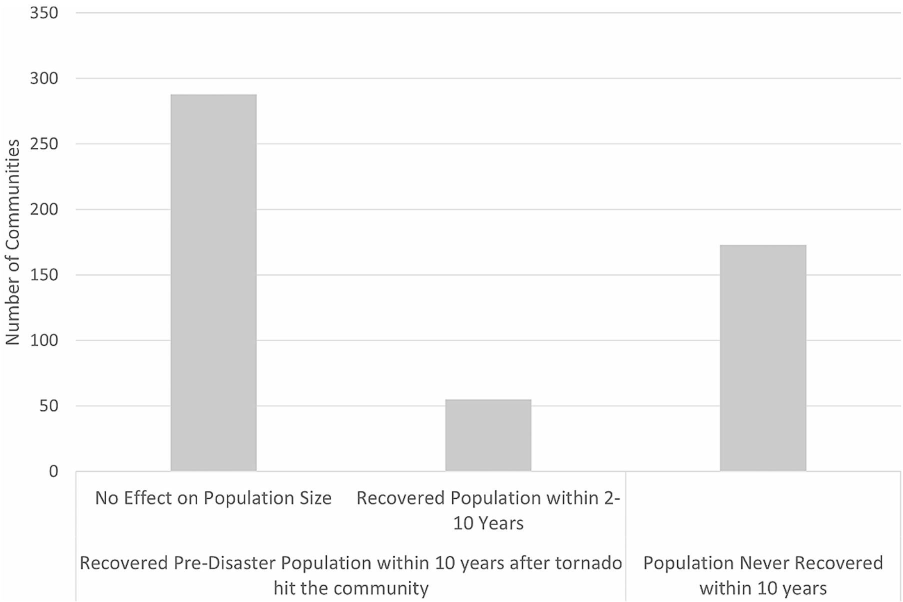

Fig. 2 Community recovery and effect on population size

Table 1 Selected determinants of population change in Tornado-affected U.S. communities

Number	Variable	Source
Determinant		
1	State status (in terms of location of Sunbelt or Snowbelt)	Sunbelt: Jewell 2020 Snowbelt: Balland and Rigby 2017
2	Community size (in terms of population size	Biggestuscities.com/city/name of the city-state name; [a] U.S. Census Bureau's census (different census years); or 5-year ACS estimates (90% confidence level)
3	Tornado strength (F/EF scale)	SPC
4	Tornado death (number)	SPC
5	Population trend (+or -) at least for two preceding decades	Biggestuscities.com/city/name of the city-state name; U.S. Census Bureau's census (different census years); or ACS
6	County seat	U.S. Census Bureau's census; City-data.com U.S. Census Bureau's census;
7	Suburb status	City-data.com
Dependent Variables		
1	No change in total population size	Biggestuscities.com/city/name of the city-state name; U.S. Census Bureau's census (different census years); or ACS
2	Recovered post-tornado population size within 2–10 years	Bigestuscities.com/city/name of the city-state name; U.S. Census Bureau's census (different census years); or ACS

of tornadoes by F/EF-scale[6] rating affects the threat to people and property (Simmons and Sutter 2011; Swienton et al. 2021). While tornado deaths appear in the table as a second independent variable, we excluded injuries for one reason. Tornado events cause a wide variety of injuries, ranging from minor to life-threatening injuries. Those who sustained minor injuries comprise the majority, most of whom do not need medical attention. Most other serious injuries require hospitalization for months. Unfortunately, the SPC tornado data do not provide information about the severity of an injury.

Unlike the U.S. Census Bureau's data, neither of these data sources is a scientific dataset. Apart from census and ACS years, all years arose from the two other sources.

The following determinant selected refers to the state attribute of whether the tornado-affected communities are in the Sunbelt or Snowbelt.[7] We expect people to move from the Snowbelt to the Sunbelt for several reasons. The Sunbelt's manufacturing activities have been growing for decades. Coupled with transportation improvements, abundant summer air conditioning and a favorable winter climate have attracted retirees and workers. However, the remaining determinants are community characteristics. Among these characteristics, we selected community size in terms of population size. This site was readily available from the U.S. Census. Where the annual population for concerned communities was unavailable in limited cases (<10), size was determined by interpolating past and subsequent U.S. Census or American Community Survey (ACS) data. The community population trend for at least two preceding decades appears as the fifth determinant in this study. The community population variable indicated whether the community was already growing or declining when struck by the tornado. A growing community may recover quickly post-tornado following its prior growth trajectory. Affected county seats or suburb status were included because these communities were relatively large, and thus, they were likely to recover the post-tornado total population quickly. County seats or suburbs' special status and location close to metropolitan areas attract the press and politicians' attention (Cross 2001).[8] Moreover, such communities have strong horizontal and vertical connections. As a result, Berke et al. (1993) claimed that "well-developed ties to external resources and programs" and "viable horizontal network that will allow exerting power and influence in the recovery process" (p. 101; see also Montz et al. 2017; Tobin and Montz 1997). The first dependent variable was defined as if the total population had not changed despite a community experiencing a tornado. The size of the population was followed for 1 year after it was struck by a tornado.

3.3 Analytical techniques

Whether tornado-struck communities had no (negative) effect on population size was used as a first response variable in this study, meaning that the affected communities returned or even increased to the pre-event population level within 1 year after the event struck. The second dependent variable considered whether the affected communities took 2–10 years

[6] From 1971 to 2007, tornado magnitude was measured on the Fujita scale or F-Scale. The Enhanced Fujita Scale or EF Scale has replaced the Fujita Scale since 1 February 2007. It was revised to reflect examinations of tornado damage surveys better, precisely to align wind speeds more closely with associated tornado damage. Both scales have six categories from 0 to 5, representing increasing degrees of damage (Paul 2011).

[7] Several maps classified the 48 conterminous United States into the snowbelt and the Sunbelt. These maps are not in complete agreement on the status of some states.

[8] A suburb is a town or small city where people live just outside a metropolitan area or a large city.

to return to the pre-tornado population size. Although tornadoes can occur any time of year, they tend to strike during particular months. The time of year when the United States experiences the most tornadoes is termed the *tornado season* and typically peaks from April–July (Brusentsev and Vroman 2017; Simmons and Sutter 2011). The study data supported those peak months. Additionally, no tornado occurred on 1 January or the last day of December of the calendar year. Often, the yearly population of the tornado-affected communities was not available. In those cases, the yearly population of the study period was calculated based on the population growth or decline trend derived from the three most recent decennial censuses (2000, 2010, and 2020).

Since both dependent variables were categorical (*yes* and *no*), applying binary logistic regression was an appropriate statistical technique for this analysis. Two models were employed to identify which factors contributed to predicting the two dependent variables (whether communities recovered population within 1 year and whether communities reached pre-tornado population within 2–10 years). Within each separate model, the best-fit model emerged based on the Akaike Information Criteria (AIC) value and statistical significance of the predictor variables (Gorsevski et al. 2006). Each model provided a direct estimate of the odds ratio (OR) for all regressor variables. Before using the logistic regression technique, a chi-square tested the crude effect of exposure variables on two dependent variables by cross-tabulation without controlling for other variables. R-Studio facilitated statistical analysis. We used the R library *stats* to run the logistic regression.

4 Results

In this investigation, the tornado selection criteria used allowed for examining tornado occurrences in the conterminous United States, comprised of 48 states. Among these, 37 states recorded tornadoes during the designated study period. While tornadoes can potentially affect all states within the country, the annual frequency of tornado occurrences varies significantly from one state to another. Traditionally recognized as a region where tornadoes are most frequent, *tornado alley* encompasses a loosely defined area in the central United States, stretching from northern Texas through Oklahoma, Kansas, Nebraska, Iowa, and South Dakota. Additionally, certain states such as Minnesota, Wisconsin, Illinois, Indiana, Missouri, Arkansas, North Dakota, Montana, and the easternmost part of Colorado, New Mexico, and Ohio have sporadically appeared in tornado alley maps (Dixon et al. 2011). However, researchers have indicated that the primary tornado alley might be shifting eastward, away from the Great Plains, with tornadoes becoming more frequent in the southeastern states of the country, an area termed *Dixie Alley* (Fig. 1; Brooks et al. 2003; Cao et al. 2021; Dixon et al. 2011, 2014; Krainz and Hu 2022; Moore and DeBoer 2019; Moore et al. 2022; Simmons and Sutter 2011). The comprehensive tornado data compiled from the Storm Prediction Center (SPC) revealed that Alabama and Illinois experienced the highest number of tornadoes, followed by Tennessee, Missouri, and Oklahoma.

In contrast, during the study period, there were no reported tornadoes in 11 states: Arizona, Delaware, Massachusetts, Montana, New York, Nevada, Oregon, Rhode Island, Utah, Vermont, and West Virginia. In those states, tornadoes are considered rare, with annual occurrences ranging from two to five and all falling below the F/EF-0 intensity level (Simmons and Sutter 2011). The study period featured an average of nearly 42 communities impacted by tornadoes yearly. The lowest number of communities (22) affected by tornadoes occurred in 2000, while the highest number (75) transpired in 2008. Additionally, data indicated that at least 29 communities experienced tornadoes twice during the study period: 18 of those communities encountered two separate tornado events in different years, seven experienced two tornadoes in the same year but on different days, and four encountered tornadoes on the same day but at different times. Twenty-five communities experienced multiple tornado events during the study period, either in different years or on non-consecutive days. The four communities that encountered tornadoes on the same day were considered a single event. Moreover, no community experienced more than two tornadoes during the study period. The study findings appear in two stages. Using cross-tabulation, we examined the raw impact of seven exposure variables on two dependent variables without controlling for other factors. As an empirical association between two variables does not necessarily imply a causal relationship, a multivariate approach was subsequently applied to estimate statistical functions that predict the behavior of the two dependent variables.

4.1 Contingency analysis

Among the 516 communities examined, approximately 55.81% (288 communities) experienced a complete recovery of their total population in the year immediately following the tornado strike (Table 2); this implies that their population sizes remained unaffected after the tornadoes struck them. Conversely, the remaining 44.19% (228 communities) witnessed a decline in their total population after being impacted by a tornado. Within this group, 55 communities restored their population to pre-disaster levels within 2–10 years after the tornado event. These cases represented approximately 10.66% of the total sample. However, 33.53% (173 communities) never recovered their pre-disaster population within 10 years after the tornadoes struck. The data illuminated the diverse patterns of population recovery observed in the aftermath of tornadoes across the studied communities, offering valuable insights into the complex dynamics of post-disaster demographics.

Most of the communities (293 or 56.78%) sit in the Snowbelt region, an expected finding considering 31 (64.58%) out of the 48 states in the conterminous United States lay in this region (citation). Regarding the first dependent variable, 288 (55.81%) of the tornado-affected communities replaced their pre-tornado population size within 1 year, indicating the tornado event had no significant impact on the population size of these communities during that period (Table 2). Conversely, the remaining 228 communities (44.19%) population did not recover within 1 year after being struck by a tornado. A relatively higher proportion of communities in the Snowbelt region achieved population recovery within 1 year compared to those in the Sunbelt region. The chi-square analysis for the first dependent and independent variables (Snowbelt versus Sunbelt states) yielded statistical significance at $p = .05 (df = 1)$, highlighting the association of the variables. However, the chi-square analysis for the second dependent variable and the same independent variable did not yield statistical significance, indicating that the long-term population recovery of communities in the Sunbelt and Snowbelt states did not significantly differ.

During the study period, the tornado-struck communities fell into four categories based on population size (Tables 3 and 2). The largest community category comprised more than 25,000 people during the tornado strike, while the smallest category comprised less than 5,000. Among the smaller communities, approximately 63.45% did not return to their pre-tornado population size within 1 year. Both dependent variables showed a consistent trend of increasing percentages of communities failing to recover to pre-disaster population size with declining community size. The relationship between community size and the replacement of population within 1 year or not proved to be statistically significant, with a chi-square value of 73.98 and $p < .000$ ($df = 3$), which also holds for the second dependent variable. We excluded F/EF0 tornadoes and categorized the remaining tornadoes (F/EF1-5) into three groups based on their perceived strength: weak (F/EF1), strong (F/EF2-3), and violent (F/EF4-5) tornadoes (Tables 3 and 2). The data revealed that among the 516 communities struck by tornadoes during the study period, approximately 51.36% experienced weak tornadoes, while 43.60% encountered strong tornadoes. Only 5.04% of communities experienced a violent tornado. These figures aligned with the annual tornado strength patterns observed in the United States.

In line with the overall U.S. pattern, most communities we examined experienced no fatalities from tornadoes. Among communities recording tornado-related deaths, most suffered only one death. Consequently, we categorized tornado deaths into two groups: (a) death and (b) no death (Tables 3 and 2). For instance, Newburn, Tennessee, witnessed the highest number of deaths when an F3 tornado in 2006 claimed 16 lives. However, the insignificant chi-square values confirmed that tornado-related deaths did not significantly affect the two dependent variables (Table 2). As expected, among the 516 communities selected for this study, approximately 44.38% showed positive population trends in at least two census years preceding the tornado strike, while the remaining 55.62% experienced negative trends (Table 3). Most communities with a positive population trend (approximately 93.01%) observed no significant effect on population growth in the 1 year following the tornado event. Conversely, the communities with negative population trends were less likely to recover to pre-tornado population levels within 1 year, which also held for the second dependent variable. The population trend emerged as the most influential factor among all independent variables considered in this study, with the largest chi-square values obtained for both dependent variables.

Among the 516 selected communities, 164 (31.78%) were identified as county seats, and 53 (10.27%) were categorized as suburbs of large cities (Table 3). The county seat status of tornado-affected communities did not significantly impact their ability to return to pre-event population size within 1 year or 10 years following the tornado strike, as evidenced by the non-significant chi-square values for both dependent variables. However, the suburbs' status significantly affected population recovery to pre-disaster levels (Table 2). Four of the seven independent variables analyzed showed statistically significant associations ($p < .05$) with the recovery of pre-event population size within 1 year or 10 years after the tornado impact. These variables, ranked in descending order of association with the two dependent variables, are population trend, community size, and suburb and state status (Sunbelt vs. Snowbelt). We incorporate all seven variables into logistic regression models.

4.2 Logistic regression analysis

Two logistic regression models were employed to investigate the factors significantly influencing the recovery of pre-tornado population size in American communities impacted by tornadoes during the study period (Table 4). The logistic regression output provides coefficient estimates, odds ratios (OR), and each variable's model fitness statistic (AIC). Among

Table 2 Contingency table analysis ($N=516$)

Independent Variable	Dependent Variable			
	Recovery of Pre-Tornado Population Within 1 Year		Recovery of Pre-Tornado Population Within 2–10 Years	
	Yes (%)	No (%)	Yes (%)	No (%)
State Status				
Snowbelt (0)	177 (60.41)	116 (39.59)	205 (69.97)	88 (30.03)
Sunbelt (1)	111 (49.78)	112 (50.22)	138 (61.88)	85 (38.12)
Chi-square	5.383 ($df=1$; $p=.020$)		3.358 ($df=1$; $p=.067$)	
Community Size				
>25,000 People (0)	74 (83.15)	15 (16.85)	79 (88.76)	10 (11.24)
15,001–25,000 People (1)	46 (73.02)	17 (26.98)	52 (82.54)	11 (17.46)
5,000–15,000 People (2)	81 (64.29)	45 (35.71)	96 (76.19)	30 (23.81)
<5,000 People (3)	87 (36.55)	151 (63.45)	116 (48.74)	122 (51.26)
Chi-square	73.981 ($df=3$; $p<.000$)		66.062 ($df=3$; $p<.000$)	
Tornado Strength				
F/EF-1 (Weak) (0)	153 (57.74)	112 (42.26)	179 (67.55)	86 (33.45)
F/EF-2-3 (Strong) (1)	121 (53.78)	104 (46.22)	148 (65.78)	77 (34.22)
F/EF-4-5 (Violent) (2)	14 (53.85)	12 (46.15)	16 (61.54)	10 (38.46)
Chi-square	1.16 ($df=2$; $p=.281$)		0.470 ($df=2$; $p=.791$)	
Tornado Death				
Death (0)	57 (50. 89)	55 (49.11)	74 (66.07)	38 (33.93)
No Death (1)	231 (57.18)	173 (42.82)	274 (67.82)	130 (32.18)
Chi-square	1.16 ($df=1$; $p=.281$)		1.254 ($df=1$; $p=.263$)	
Population Trend				
Positive (0)	213 (93.01)	16 (6.99)	227 (99.13)	2 (0.87)
Negative (1)	75 (26.13)	212 (73.87)	116 (40.42)	171 (59.58)
Chi-square	228.81 ($df=1$; $p<.000$)		194.36 ($df=1$; $p<.000$)	
County Seat				
No (0)	188 (53.41)	164 (46.59)	225 (63.92)	127 (36.08)

Table 2 (continued)

Independent Variable	Dependent Variable			
	Recovery of Pre-Tornado Population Within 1 Year		Recovery of Pre-Tornado Population Within 2–10 Years	
	Yes (%)	No (%)	Yes (%)	No (%)
Yes (1)	100 (60.98)	64 (39.02)	118 (71.95)	46 (28.05)
Chi-square	2.299 (df=1; p=.129)		2.887 (df=1; p=.089)	
Suburb Status				
No (0)	240 (51.84)	223 (48.16)	292 (63.07)	171 (36.93)
Yes (1)	48 (90.57)	5 (9.43)	51 (96.23)	2 (3.77)
Chi-square	27.376 (df=1; p<.000)		21.999 (df=1; p<.000)	

Note. *Reference category is indicated by 0

Table 3 Distribution of the selected 516 communities by independent variables

Independent Variable	Number	Percentage
State Status		
Snowbelt	293	56.78
Sunbelt	223	43.22
Community Size		
>25,000 People	89	17.25
15,001–25,000 People	63	12.21
5,000–15,000 People	126	24.42
<5,000 People	238	46.12
Tornado Strength		
F/EF-1	265	51.36
F/EF-2–3	225	43.60
F/EF-4–5	26	5.04
Tornado Death		
Death	112	21.71
No Death	404	78.29
Population Trend		
Positive	229	44.38
Negative	287	55.62
County Seat		
No	352	68.22
Yes	164	31.78
Suburb Status		
No	463	89.73
Yes	53	10.27

the independent variables, two were statistically significant—negative population trend and communities with less than 5,000 people—one with a significance level of $p<.001$ and the other with a significance level of $p<.01$. The logistic regression analysis revealed that the negative population trend is the most influential predictor in explaining the recovery of pre-tornado population size within one year in the affected communities, as it was statistically significant at $p<.001$. The negative population trend exhibited the highest odds ratio of 29.21, indicating that tornado-affected communities experiencing a positive population trend were approximately 29 times more likely to return to their pre-tornado population size within 1 year than those with negative population growth. Similarly, reference communities (with more than 25,000 people) were 3.24 times more likely to recover their pre-tornado population size than the smallest communities with less than 5,000 people, and this difference was statistically significant at $p<.01$. However, the other two categories of community size were insignificant predictors (Table 4). While the odds ratios decreased with increased community size, the reference communities remained 1.5 times more likely to recover their population within 1 year than their immediate second-largest counterparts (with a population between 15,001 and 25,000; Tables 2 and 4).

In Model 1, among the three sizes of communities, only the smallest community size (i.e., less than 5,000; Table 4) demonstrated statistical significance. The community size category 2 (5,000–15,000 people) came close to reaching significance at $p<.05$. The reference category for the smallest community size, in terms of the independent variable, was the community size with more than 25,000 people. The three non-reference categories of this variable displayed odds ratios greater than 1, suggesting that these community sizes have higher odds of recovery than the largest community size (greater than 25,000 people). Moreover, this implies that smaller tornado-affected communities require a longer time to recover to their pre-event population size than larger communities. The odds consistently increased with decreasing community size, with the smallest community exhibiting the highest odds ratio of 3.24 (Table 4). The remaining five independent variables were not statistically significant, although they displayed expected signs and odds ratios. Notably, one independent variable showed a negative sign, as anticipated. Communities that did not experience any tornado-related deaths during the study period recovered within one year compared to those communities that encountered the death of one or more individuals.

Model 2's dependent variable pertains to whether the tornado-affected communities returned to their pre-disaster population within 2–10 years (Table 4). Similar to Model 1, the same independent variables were included in Model 2. Also consistent with Model 1, population trend and intercept were statistically significant at $p < .001$. However, the remaining independent variables were not statistically significant. The interpretation of odds ratios remains consistent with the discussion on Model 1 (Table 4). The data demonstrated a better fit in Model 2 than Model 1, as evidenced by the lower AIC value for Model 2 (418.54 versus 451.0).

Table 4 Logistic regression results

Explanatory Variable	Model 1		Model 2	
	Model Fitness Statistics (AIC)			
	451.0 418.54			
	Estimate	OR	Estimate	OR
Intercept	-4.166**	0.016	-6.291**	0.002
State Status				
Sunbelt (1)	0.100	1.105	-0.022	0.978
Community Size				
15,001–25,000 People (1)	0.431	1.538	0.095	1.100
5,000–15,000 People (2)	0.854	2.348	0.444	1.559
<5,000 People (3)	1.176*	3.241	0.894	2.455
Tornado Strength				
Strong, F/EF 2–3 (1)	0.419	1.521	0.191	1.211
Violent, F/EF 4–5 (2)	0.750	2.118	0.836	2.307
Tornado Death				
No (1)	-0.471	0.624	-0.288	0.750
Population Trend				
Negative (1)	3.375**	29.213	4.818**	123.727
County Seat Status				
No (1)	0.214	1.239	0.276	1.317
Suburb Status				
No (1)	0.636	1.889	0.994	2.702

Note. *$p < .01$; **$p < .001$. The reference category is indicated by 0 in Table 2

5 Discussion

We used two logistic regression models, each incorporating seven predictor variables, to examine the factors contributing significantly to the recovery of pre-tornado population size in American communities impacted by tornadoes during the study period (Table 4). The chi-square test was initially applied, revealing that four independent variables (state status, community size, population trend, and suburb status) exhibited statistical significance in Model 1, focusing on population recovery within one year. Subsequently, through logistic regression, two variables, namely community size with fewer than 5,000 people and population trend (both community factors), emerged as significant predictors in this model. In Model 2, which pertained to population recovery within 2–10 years, three independent variables (community size, negative population trend, and suburb status) showed significance in the bivariate analysis. However, only the population trend remained significant in the multivariate situation. It is noteworthy that aside from tornado events, many rural communities across the United States have experienced persistent population loss, especially in remote small communities (Johnson 2022). More people have left nonmetropolitan (rural) counties than relocating to them, resulting in a natural population decrease due to higher death rates than birth rates (Cromartie et al. 2015; Slack and Jensen 2020).

In Model 2, the smallest community size did not demonstrate statistical significance. Eighty-seven of the smallest communities recovered at least the base population within 1 year after the tornado struck them (Model 1). In contrast, in Model 2, 116 of the smallest communities achieved pre-tornado population size within 2–10 years (Table 2). The additional recovery of 29 communities in Model 2 might link to the implementation of incentives provided by community leaders to discourage population loss after the tornado event. We did not collect information regarding post-tornado policies adopted by these and other tornado-affected communities during the study period. However, empirical studies have suggested that such policies and supports play crucial roles in facilitating the rapid recovery of tornado-affected communities and the subsequent increase in their population (Brock & Paul, 2003; Paul and Che 2011; Paul and Stimers 2015). The enforcement of costly safety measures during repair and rebuilding processes and restrictive zoning ordinances delays recovery efforts and acts as barriers to regaining pre-tornado population size (Paul 2011; Smith and Sutter 2013). Conversely, tax incentives encouraging residents to rebuild houses in tornado-affected communities foster reconstruction and population retention (Dvorak and Wiebe 2003; Paul and Stimers 2015). We not only considered one physical characteristic of tornadoes, i.e., magnitude, which in both bivariate and multivariate analyses did not show statistical significance (Tables 2 and 4). The result was unsurprising, as strong and violent tornadoes rarely strike communities, with the United States experiencing approximately one EF-5 and 10 EF-4 tornadoes yearly. Furthermore, only about 20% of tornadoes result in fatalities, and most fatal tornadoes claim just one life (Simmons and Sutter 2011).

The same applies to the state status, whether Sunbelt or Snowbelt, which was not significantly associated with population recovery. The desire of many elderly individuals from the Snowbelt to relocate to the Sunbelt, particularly in states like Arizona and Florida, to avoid cold weather and snow has been well-documented (Simmons and Sutter 2011). However, it appears that either enough elderly individuals from tornado-affected communities in Snowbelt states did not migrate to the Sunbelt, or elderly individuals from the Sunbelt did not move to the former affected communities, mainly since the Sunbelt experienced stronger and more violent tornadoes than Snowbelt states during the study period. Notably, since 2000, killer and high-magnitude tornadoes have shifted from Snowbelt states to Sunbelt states, particularly in the southeast, where there are higher population densities, lower-income populations, and more obscured views of twisters due to increased tree coverage (Borenstein 2022).

The county seat status of tornado-affected communities did not emerge as a significant predictor in both bivariate and multivariate analyses (Tables 2 and 4). One plausible reason for this lack of significance is the wide distribution of tornado-affected places across all community sizes. The data indicated that out of the 316 selected communities, 164 were designated county seats, encompassing all four community size categories considered in this study. The smallest community size category accounted for nearly 31% of these county seats, while the largest size category represented 26%. Additionally, over a dozen county seats were suburbs of metropolitan areas. Particular communities experienced tornadoes multiple times during the study period. For instance, Leesburg, Virginia, was struck twice in 2003 (July and November). Benton, AR, and Owensboro, KY, were struck by tornadoes three times each during the study period. However, we excluded this variable from the analysis due to the relatively small number of such communities. Similarly, the mean or median annual income, another community-level variable, was excluded primarily due to a lack of relevant data for the study years.

We focused on seven factors while excluding other potential factors primarily due to data unavailability for each tornado-affected community and during the study period. For instance, the implementation of incentive programs by tornado-affected communities and the provision of timely tornado warnings are crucial factors influencing population retention or loss in these communities. Future research could adopt a smaller sample size and conduct interviews with authorities from the affected communities to gain insight into their post-tornado policies and strategies to overcome these limitations. Additionally, socioeconomic, race/ethnicity, employment, and poverty factors could be considered in future investigations, although only for some study years in small and medium-sized communities.

However, the study revealed that four factors demonstrated significance in the bivariate analysis (state status, community size, population trend, and suburb status), and two factors (population trend and community size) remained significant in the multivariate situation in Model (1) Similarly, three variables (community size, population trend, and suburb status) showed significance in the bivariate analysis, with only the population trend remaining significant in the multivariate situation in Model (2) Multivariate analyses emphasized the significance of the population trend as an essential determinant in both models for population recovery within one year or 2–10 years after tornado events. Consequently, community leaders and disaster managers should exercise caution, especially in smaller communities (<5,000 people) experiencing negative population trends before and immediately after a tornado event. Community leaders must exert all efforts to retain the population and discourage relocation to other communities following the disaster.

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Data availability Data used in the research is publicly available (a) U.S. Census Bureau data and (b) National Weather Service data, aligned with the dates listed in the manuscript, or (c) regarding the Stimers

(2011) dataset, used with permission from Mitchel Stimers, and freely available at https://krex.k-state.edu/handle/2097/8531.

Declarations

Conflict of interest No authors have financial interests in this manuscript.

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