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Historical Santa Barbara up in flames: A study of fire history and historical urban growth modeling

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Noah C. Goldstein
Jeannette T. Candau
Max A. Moritz

Abstract

Wildfires and urban environments are at odds when cities are built near fire-adapted landscapes. We examine the history of these co-evolved phenomena by observing how the wildfires of Los Padres National Forest (LPNF) have burned the urban extent of Santa Barbara, California and its environs. The urban extent data was created by "backcasting", the process of interpolating the missing urban extents in a sequence of historical data. We obtained digitized GIS fire history data of LPNF, a chaparral dominated landscape. We identified 7 fires that burned urban extent in the period of 1929 to 1991. After the fires, all of the urban extent was rebuilt. In one case, the urban extent was burned twice, once in 1955 and again in 1990. Analysis of the burnt urban extent indicates that as the city grows, the percentage of urban areas lost to fires increases. We propose this is because; 1) the city is responsible for increased fire ignitions, 2) the urban extent is growing towards the sources of the fires and, 3) the city is not changing its behavior to respond to the fires.

Keywords

Fire history, urban growth, cellular automata, evolution of systems, effects of fire.

Introduction

Wildfires have been affecting the urban landscape since its inception. Over time, the process of urbanization and the dynamics of wildfires have been co-evolving as they react to each other and compete for space in a number of complex ways. The way in which each system reacts is different. Urban areas influence the wildfire system by altering fire ignition and extinction, and by altering social behavior (e.g., by banning fireworks and passing building and landscaping ordinances). The wildfire system responds to urbanization by burning it, but in patterns that change over time to reflect growing ignition sources and the increased or decreased flammability of developed areas. It is clear that fire suppression technology has improved over time, and this has had different impacts in different regions. What is not clear is whether urban systems can "learn" from past events in a wildfire system to minimize future interactions.

This study examines the historical relationship between these two systems for the region surrounding Santa Barbara, California, using the fire history for Los Padres National Forest (LPNF). By examining the growth of urban extent in this region over time, in conjunction with the amount of urbanized area burned over time, we hope to identify feedbacks between the urban and wildfire systems. If the percentage of urbanized area burned over time is constant, we might conclude that increasing ignitions are successfully being offset by post-fire rebuilding and urban development that has "learned" from past fire events. If, on the other hand, we see a growing percentage of the urban extent burning over time, we may conclude that little "learning" has taken place through the interaction of urban and wildfire systems. We conclude with a discussion of errors in our analysis and how future studies can elucidate the co-evolution of these two dynamic systems.

Background

Urban history / prediction

The Santa Barbara region is located along California's south coast, 100 miles Northwest of Los Angeles. Situated between the Pacific Ocean and Santa Ynez Mountains, Santa Barbara's growth has occurred largely on the gentle slopes between the two. The area was originally inhabited by the Chumash Indians, who subsisted in the region through hunting, farming, and fishing. In 1782 the Spanish settled in Santa Barbara and used the land for ranching as well as farming and of course, building homes. Santa Barbara was relatively isolated and growth was moderate until the middle part of this century. Goleta, west of downtown Santa Barbara, saw a large boom in the early 1940s with the onset of World War II and the construction of the Santa Barbara Airport. There was conversion over this period from range land to orchards, farming, and light industry. The entire region underwent rapid growth in the post W.W.II era as America fled to the suburbs. This trend continued until the early seventies when the demand for new homes slowed, and easily settled land with moderate slopes became filled. For the past decades growth has generally leveled off and is now largely limited to infill and high density housing.

LPNF is located along the central Coast Ranges and Transverse Ranges of California and is divided into the Main and Monterey Divisions (~585 000 and 125 000 ha, respectively). Urban Santa Barbara abutts the southern boundary of the Main Division. Annual precipitation in the Main Division ranges from 250 to 1 000 mm (Davis and Michaelsen 1995), and the climate is Mediterranean (i.e., cool, moist winters with hot, dry summers). LPNF contains portions of the Central Western and Southwestern ecological regions of California, as delineated in Hickman (1993). The vegetation is predominantly chaparral and coastal sage scrub, both of which are fire-adapted shrublands.

The City of Santa Barbara and its environs have an extensive rural interface with LPNF. Periodic wildfires, frequently the result of arson, impact the region by temporarily removing flora and fauna from the landscape, increasing the local rates of erosion, decreasing air and water quality, and destroying public and private property (Barro and Conrad 1991). The dollar amount of damage to infrastructure and property has been reported at hundreds of millions of dollars for the 1990 Santa Barbara fires alone (Clarke and Gaydos 1998). There is disagreement over how the fire regime would vary in California shrublands in the absence of human activities.

The most contentious issue is whether large fires are a normal aspect of the fire regime or a direct result of fire suppression (Keeley et al. 1999, Minnich 1983, Minnich and Chou 1997, Moritz 1997). Although LPNF has a history of fire suppression, sediment cores from the Santa Barbara Channel indicate that large fires have been occurring nearby for centuries (Byrne et al. 1977, Mensing et al. 1999). These findings suggest that large fires are a natural part of chaparral ecology and not the result of fire suppression. Moritz (1997) analyzed the distribution of large fires in the modern LPNF fire regime and found that suppression has not altered the likelihood of large fires over time. Keeley et al. (1999) also discounted the impact of fire suppression in California shrubland ecosystems, finding that fire frequency and area burned have not declined, nor has fire size increased, over time. Instead, they suggest that fire suppression is probably offsetting large increases in ignitions due to human population growth in the region, and short fire intervals are identified as an ecological concern. In a comprehensive analysis of historical burning patterns, Moritz (1999) concluded that the age of fuel does not limit fire spread in LPNF during extreme fire weather conditions, indicating that large fires are probably routine events in many shrubland ecosystems and not the result of fire suppression. However, little work has been done to identify changes in fire frequency and size at the urban-wildland interface. The Santa Barbara area is also unique, in that it is topographically sheltered from most extreme fire weather events (i.e., Santa Ana winds) that routinely impact California's shrubland-dominated ecosystems.

For the purposes of this study, the “wildfire system” is the general term given to the ecological dynamics and structure of fire adapted vegetation (i.e., burning and regrowth under the current fire regime). A fire extent is thus the expression of local ecology, given specific weather conditions and an ignition source. Once ignited, a fire responds to the topography, wind, and moisture content of the vegetation, as well as the activities of firefighters.

Methods

Available data

A historical profile of urban growth in Santa Barbara was constructed in a temporal GIS database (Acevedo, et al 1996) with an Albers projection. All structures present in areal photographs for the years 1929, 1942, 1952, 1967, 1975, 1986, and 1997 were digitized. These include buildings present on park or forest lands. The vector coverages were transformed into 30 m raster grids, which were classified as urban or non-urban. These data only describe urban extent, and are not related to density or property lines. A digital fire history of LPNF is currently maintained in a Geographic Information System (GIS) and it spans the period 1911 to 1995. One GIS coverage contains all known ignition locations, which are points with several fire-related attributes (e.g., start date, fire name, and cause), regardless of the fire's eventual size. Another coverage contains mapped perimeters of were greater than ~125 ha in size. It should be noted that historically, fires outside the LPNF boundary were not mapped in a consistent way, unless they came close enough to threaten Forest lands (F. Cahill, retired LPNF, personal communication). Moritz (1999) found through visual inspection that burned areas within a 3200 m buffer of the LPNF boundary appear to be mapped consistently, and this was chosen as the limit of the GIS fire database for the LPNF. Although this is a somewhat arbitrary distance, it is a reasonable tradeoff between excluding a great deal of valuable information (i.e., by stopping analyses at the LPNF boundary) and including areas exhibiting mapping bias (i.e., by including the area of all mapped fires in the dataset). Mapped fire histories can contain errors introduced during the original fire mapping effort or during transfer to newer maps. In comparing old fire history maps, Moritz (1999) infrequently found fire perimeters to vary by up to ~500 m; therefore, original maps were used instead of copies for digitizing fire perimeters, where possible. This issue is not as important for recent fires, which are mapped in a more reliable manner (e.g., remote sensing and verification with a global positioning system). Fire ignition points were imported into a GIS from a non-spatial database, which contained estimated coordinates of the start of each fire. These locations are accurate within a radius of ~800 m (F. Cahill, retired LPNF, personal communication).

Urban Backcasting

To quantify the percentages of urban extent burned over time, we needed to “back cast” urbanization to obtain spatial patterns of development that existed at the time of each historical fire in our study area. Historical data of urban area for the burn years were needed for intersect analysis. The modified cellular automaton Clarke Urban Growth Model (Clarke, Hoppen, Gaydos 1996) was used to interpolate urban extent from the years of known data. This process is called “backcasting”. An extensive calibration of the model for the Santa Barbara area was performed (Candau 2000, Clarke, Hoppen, Gaydos 1996). For calibration, the earliest urban year is used as a seed, and the model will iterate uninterrupted through growth cycles, until the last data year is reached. A modification of this technique was used to limit growth to the spatio-temporal constraints of the control data. Each control year was used as a seed, and the model was run until the next known date. Additionally, the non-urban area of the following control year was used as an exclusion, or non-urbanizable, layer. This forced the model's growth to occur only within areas that were actually built upon. In this way the model generated a grid of urban extent that temporally matched the burn dates on an annual time scale.

The fire extents were first clipped with the urban extent of 1997 to remove excess data. The resulting fire maps were rasterized using the Polygrid function in ArcInfo. The cell size was chosen to be 30m, matching that of the urban data. Once rasterized, the fire coverages were separated by fire number. Each fire extent then became its own grid. Fire grids were then combined with the backcasted urban grids by using the AND function in ArcInfo GRID, where pixels which appeared in both grids received a value of 1 and all others received a value of 0. A fire in a given year was intersected with the urban extent for that year, assuming all urban growth would have been “in progress” or completed by the time the pixels were burned. The intersected extents of wildfires and the backcasted urban extents were then analyzed to quantify how much urban area burned in each fire and what percentage of total urban extant burned at that point in time.

Findings

There were seven fire-urban intersections between the years 1929 and 1992. See Table 1 for a breakdown of each fire event. Figure 1 shows the relationship between the total urban extent at the time of each fire and the percentage of urban extent burned in that fire.

Fire name	Fire Date	Cause	Total Fire Size (ha)	Total Urban Extent of Santa Barbara	Total Urban Extent burned by wildfire (ha)
Refugio	1955-09-06	Burning Building	34306.42	3295.17	0.27
Polo	1964-03-07	Powerline	236.75	4125.69	1.89
Coyote	1964-09-22	Unknown	27114.90	4125.69	8.19
Romero Canyon	1971-10-06	Incendiary	5883.53	7469.73	1.71
Sycamore Canyon	1977-07-26	Kite on Powerline	325.78	9040.59	139.68
Eagle	1979-09-18	Unknown	1833.29	9129.06	51.12
Painted Cave	1990-06-27	Wildland Arson	1726.90	10185.48	368.91

Table 1. Results from intersecting the backcasted urban extents of Santa Barbara with the historical wildfires of the LPNF.

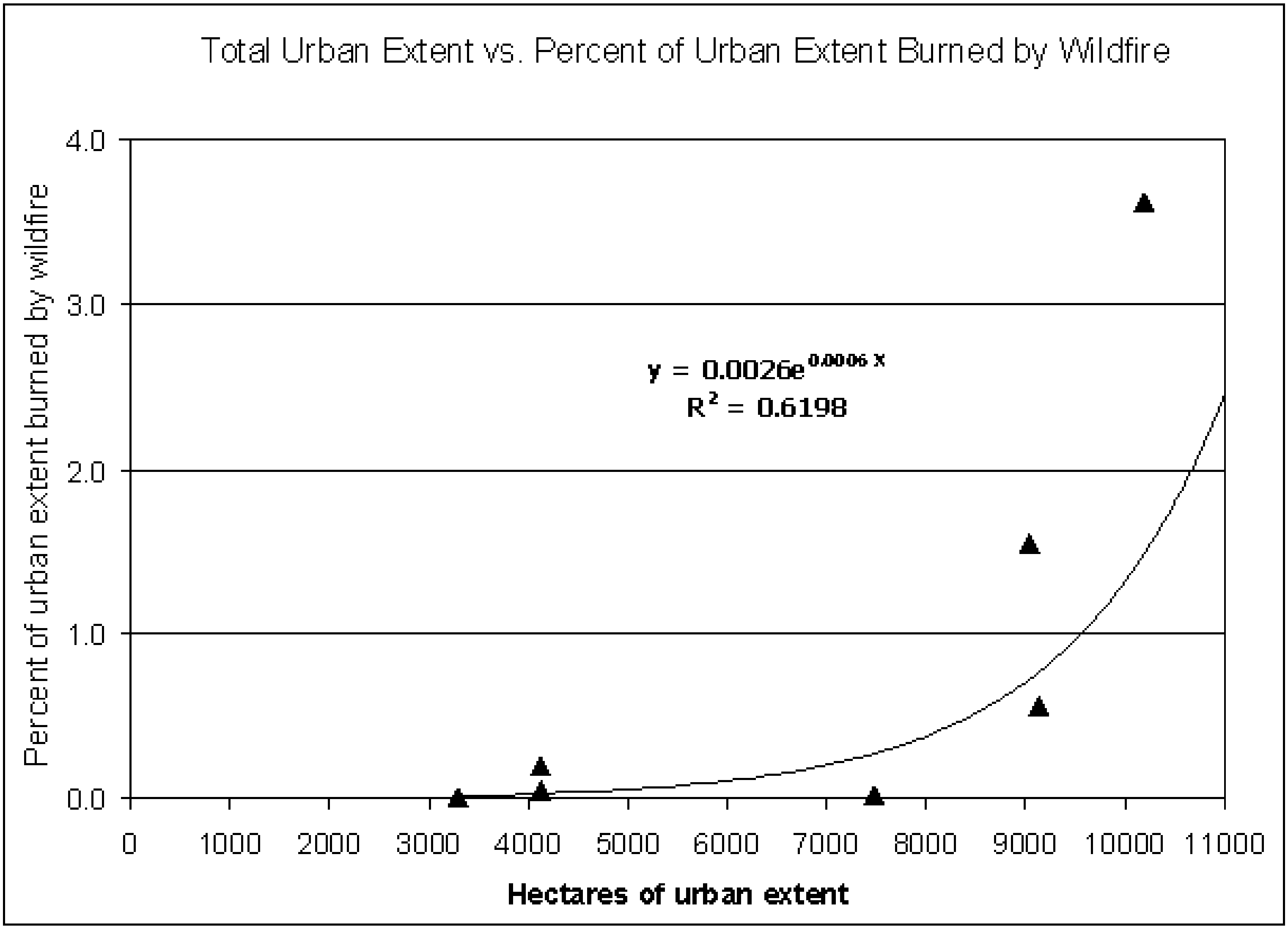

Figure 1. Urban extent of Santa Barbara vs. percent urban extent burned.

Discussion

There are many ways that humans can start fires, some by accident, some intentional. It is interesting to note that some sort of human activity or structure caused five out of the seven fires that eventually burned into urban extent at the time. The “unknown” causes are also probably due to humans, as lightning ignitions near in LPNF uncommon and would be well-documented (Moritz 1999). On the other hand, humans spend a great deal of time and money trying to reduce ignition sources and to suppress fires. This is particularly important in the Santa Barbara region due to the fire-adapted vegetation covering most of the landscape. Whatever their intent, humans clearly influence the wildfire system, which subsequently impacts the urban environment in which humans live. Our findings highlight this relationship and its inherent feedbacks.

Fire suppression efforts, while improving with advances in technology, e.g., aerial firefighting techniques, established in the 1950’s, are hampered by urban-wildland interfaces that are long and complex. As urban Santa Barbara grows, the urban-wildland interface gets more expansive and populated, resulting in a greater percentage of the urban extent being vulnerable to wildfires (Figure 1).

In fact, that trend appears to reflect exponential growth, although it may be unrealistic to extrapolate beyond the ranges shown here. Regardless, what we do not see is a constant or decreasing trend to indicate some type of "learning" that the urban system is capable of, in the face of ever increasing ignition sources. Further evidence against "learning" is the fact that all of the urban area burning in the 1955 Refugio Fire burned again in the Painted Cave Fire of 1990.

One may note that relatively small percentages of the total urban extent are being burned in each fire; however, this does not equate to small percentages of total area burned, nor does it reflect monetary damages. While the most recent wildfire event, the Painted Cave Fire of 1990, burned only 3.6% of the total urban extent at the time, 21.4% of that fire was in the urban area. The Painted Cave fire, which was caused by arson in ideal fire conditions, destroyed 673 buildings and caused $250 million in total damage. Similarly, the Sycamore Canyon fire burned only 1.5% of Santa Barbara's 1977 urban extent, but 42.9% of that fire was the burning of urban extent.

Sources of errors

There are numerous sources of error in this study as different people gathered much of the data from different sources. Errors in the fire maps were discussed above. Because fires more than 3200 m from the LPNF border were not mapped consistently, a few small wildfires may have been left out of the database. In addition, the rasterizing of the fire maps distorted the shape and extents of fires. This had the most impact on the fire extent's boundary, which is also where the urban-wildland interface occurs. However, this distortion is assumed to be minimal, in comparison with the size of typical fires.

The urban extents and backcasting of the missing urban extents is a source of error as well. First, the data were generalized to 30m, to conform to the UGM input, which in turn matched the highest resolution Digital Elevation Model (DEM) and other available data. Secondly, how to actually define an urban pixel is an issue. Since the UGM input was determined from aerial photography, it is appropriate that whatever appeared urban, was deemed urban. But, what is the "urban-ness" of a small storage shed, surrounded by chaparral? These issues need resolution.

Lastly, the backcasting process itself is in a state of flux. For this study, the backcasting was done once for the period 1929 to 1997. Future studies will use a Monte Carlo approach to backcasting; the urban extent will be backcasted 100 (or more) times, providing a probabilistic backcasting of urban extent. The software used for backcasting, UGM version 2.1 is currently being updated to UGM 3.0, to be made available this fall. The algorithms that urbanize a landscape will be improved and the resultant outcome of the backcasting may be different.

Given the uncertainties described above, further work is necessary to examine the 1955 fire. The burned urban extent consisted of only three pixels of 0.27 ha (2700 sq. m). It is possible that overlap between the Refugio fire and the Santa Barbara urban extent may be visible only by amplification of noise in the modeling process.

Conclusions

We have identified a clear feedback between a growing urban system and the wildfire system of its surrounding environment. With a growing urban extent over time and the expanding urban-wildland interface that accompanies it, we see a much greater increase in the percentage of urban extent burning than one would expect. This trend (Figure 1) appears to be one of exponential growth, in fact. This is somewhat startling, given that fires in our study area can only come from a limited number of directions (i.e., Santa Barbara borders the ocean). In addition, it implies a convolution of the urban-wildland interface far greater than simple perimeter-to-area ratios (e.g., a circle) and a population that is rich with ignition sources.

In contrast, there appears to be little or no feedback between the wildfire system and our urbanizing study area, which displayed no change in behavior in response to a fire. This is evidenced by the fact that every urban pixel that was burned from 1955 to 1990 was re-urbanized subsequently. Some urban areas were even burned twice in this time period (i.e., a few pixels in both the 1955 and 1990 fires), although there is some question about the spatial accuracy in this particular case. Regardless, fire management and city planning efforts in the Santa Barbara region may be overlooking the following fundamental issues in their reaction to the wildfire system: 1) Wildfires burning under extreme weather conditions will be inevitable events in many shrubland ecosystems; 2) Allowing development along a convoluted urban-wildland interface not only hampers fire suppression efforts during a fire, it also increases exposure to ignition sources that can start fires and burn into urban areas; and 3) Rebuilding after fires and allowing further growth into fire-prone areas increases the likelihood of future disasters which could possibly be prevented.

Recommendations for future research

There is much room for future research of the co-evolution of the urban-wildfire system. Much work still needs to be done on re-creating the history of these systems. Other sources of data include using fire insurance maps for estimates of fire hazard and incorporating a more precise urban extent to be used in the urban backcasting, by obtaining building records of when structures were actually re-built. In addition, there is the non-spatial data to incorporate, such as population, urban density, and zoning ordinances, which will provide more insight into the co-evolution of these systems, albeit not an explicitly spatial one.
Other points of future research include:

1. Determining the point of origin of the fires to the closest urban pixel burned.
2. Examining the point ignition maps for fires that occurred in urban extent.
3. Correlating wildfires of all sizes with historical road extents.
4. Running the backcasting in smaller timesteps, monthly or quarterly, instead of annually, which may reflect the actual growth of a city relative to fire regime.
5. Researching the frequency, size and distribution of urban fires, to create an “urban fire regime” as well as looking for cases where urban fires, started within the urban core, spread to the surroundings wildlands.

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Authors

Noah C. Goldstein, Department of Geography
University of California at Santa Barbara, Santa Barbara, CA, USA 93106.
Email: noah@geog.ucsb.edu, Tel: +1-805-893-4519, Fax:+1-805-893-3146.

Jeannette T. Candau, United States Geological Survey and Department of Geography
University of California at Santa Barbara, Santa Barbara, CA, USA 93106.
Email: nette@geog.ucsb.edu, Tel: +1-805-893-5178, Fax:+1-805-893-5178.

Max A. Moritz, Geography Faculty, Social Sciences Department
California Polytechnic State University, San Luis Obispo, CA USA 93407.
Email: mmoritz@calpoly.edu, Tel: +1-805-756-6261, Fax:+1-805-756-7019.