Environmental Costs of Urban Sprawl: Evidence from the Southern California Wildfires

Stephanie Kestelman
Harvard University

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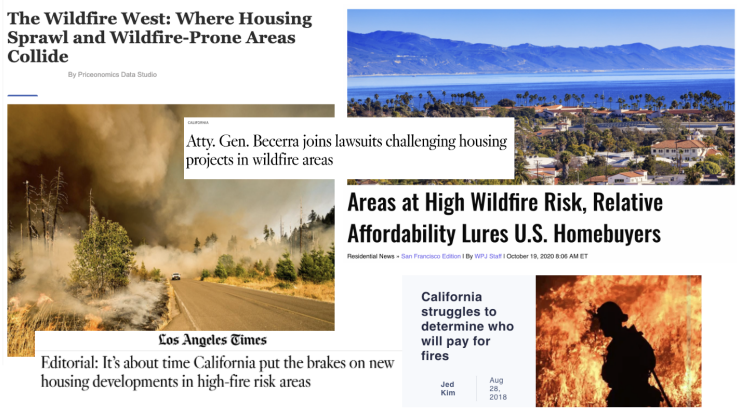
Motivation

- City shape causally impact wages and economic activity
  - Harari (2020) finds that real wages are higher (lower) in more compact (sprawled) cities
- Estimates of costs of sprawl have been limited
  - E.g., Kahn (2000) and Glaeser and Kahn (2010) on pollution; Glaeser, Kahn and Rappaport (2000) and Brueckner and Helsley (2000) on income segregation
- Available evidence $\Longrightarrow$ on balance, sprawl is not so costly...
- ... but sprawl can have other costs not yet measured
- **This project:** does urban sprawl increase the incidence and cost of wildfires?

Why wildfires?

Source: Mietkiewicz et al 2020

- Urban fringe accounts for 11% of US land area, but originated 32% of all wildfires between 1992 and 2015
- Potentially direct relationship with sprawl



This project: focus on Southern California

- Southern California Megalopolis: Los Angeles + San Diego metro areas
  - Counties included: Los Angeles, Orange, Riverside, Kern, Ventura, San Bernardino and San Diego (defined using commuting patterns)
- 30% of land is at moderate to very high wildfire potential
- In 2020, at least 410,000 residences were in areas with elevated wildfire risk ($203 billion in total reconstruction value)
  - 407,000 are single family homes
  - Both mansions and mobile homes are in the line of fire

‣ Map of 2017 fires

- Site of 4 of the costliest and 3 of the deadliest wildfires in the US until 2020
- Strict land use regulations near urban cores (Glaeser et al., 2006; Saiz, 2010; Kahn, 2011)
  - 100+ jurisdictions regulating housing supply across the megalopolis

Literature

- Causes and implications of urban sprawl
  - Glaeser, Scheinkman and Shleifer (1995); Brueckner (2000); Overman and Ioannides (2001); Black and Henderson (2003); Glaeser and Kahn (2004); Burchfield, Overman, Puga and Turner (2006); Harari (2020)
- Environmental costs of cities
  - Bento, Franco, Kaffine (2006); Glaeser and Kahn (2010); Gaigné et al. (2012); Kahn and Walsh (2015)
- Costs of housing supply restrictions, insofar as they might cause sprawl
  - Glaeser, Gyourko and Saks (2005); Saiz (2010); Gyourko and Molloy (2015); Hsieh and Moretti (2018)

Outline

1. Data
2. Wildfire risk in Southern California
3. Urban sprawl and fire risk
4. Regression results
5. Conclusion and next steps

Data

Data sources

- **Land cover:** raster data from the National Land Cover Database
  - Available 2001, 2004, 2006, 2008, 2011, 2013, 2016, 2019
- **Population:** raster data from WorldPop.org, measuring people per pixel
- **Drought:** monthly data from U.S. Drought Monitor, determining whether any part of the US is affected by drought and how severe the conditions are
- **Fire perimeters:** individual fire boundaries and causes from Integrated Reporting of Wildland-Fire Information (IRWIN) and National Interagency Fire Center (NIFC)
  - Unfortunately, can't see where the fire started
- **Wildfire Hazard Potential:** constructed by USDA using simulations of ignition and spread ‣ Overview of USDA methodology
- **Potential cost of wildfires:** proxied using assessment and transaction data from ZTRAX

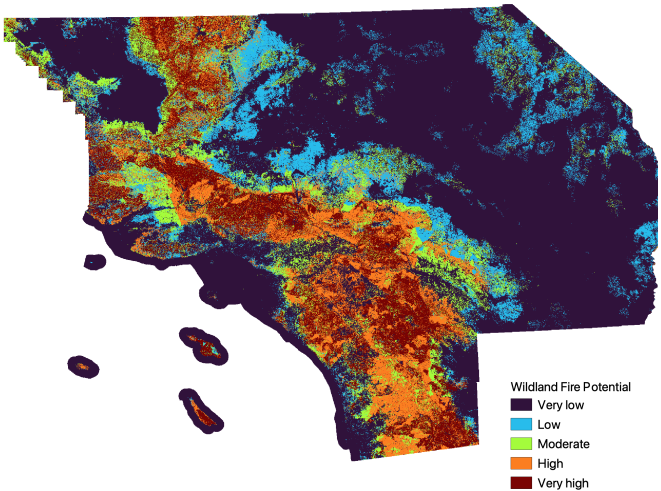
Data build overview

1. Download geographic layers (rasters and polygons) from publicly available sources
2. Reproject all the layers to ESPG 3310, which is centered around Southern California and maintains distance (in meters)
3. Build a 100m-by-100m grid and link every point in the grid to panel and cross-sectional attributes and outcomes

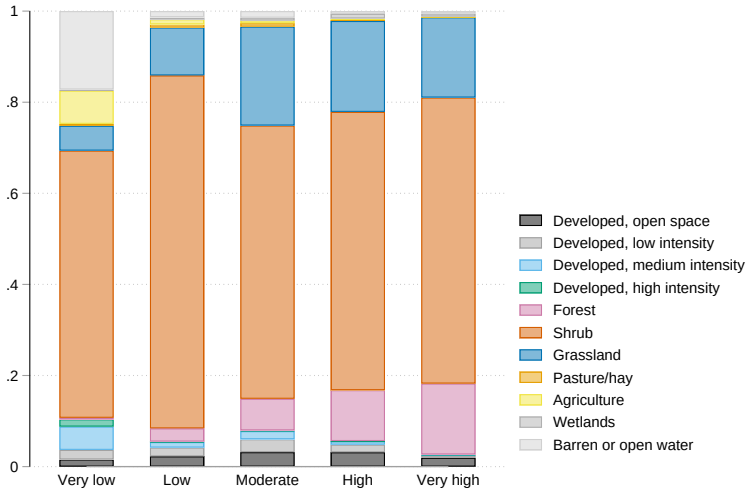
▸ Pooled summary stats ▸ 2001 summary stats ▸ 2019 summary stats

Wildfire risk in Southern California

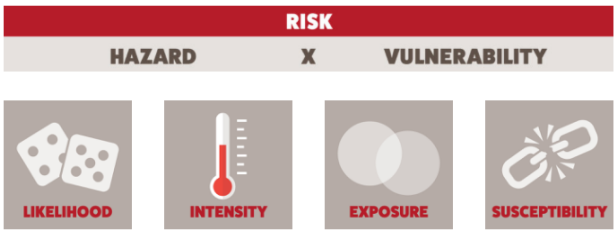
20% of the LA/SD area is at high risk for wildfire that would be difficult to suppress or contain



Developed and undeveloped areas are at high risk of extreme fire



How might sprawl increase wildfire risk?

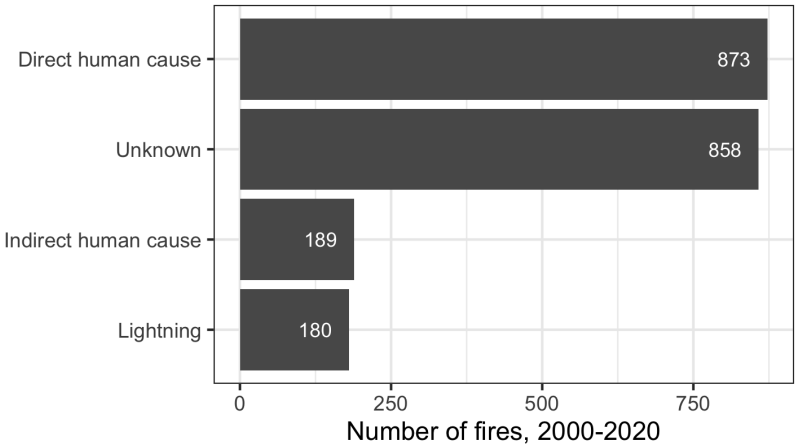


Humans interact with burn probability as follows (Radeloff et al. 2018):

- Increased probability of ignition/spark (↑ exposure and ↑ likelihood)
- Houses may serve as fuel (↑ susceptibility)

Most fires between 2000 and 2020 had direct human cause

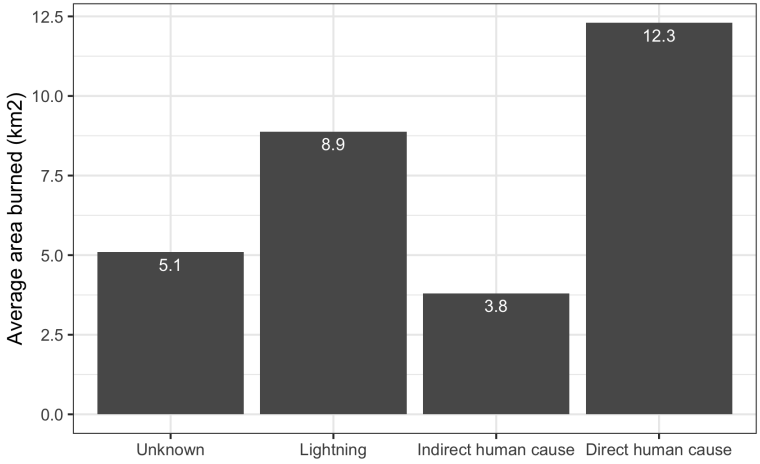
Calculated using data from Integrated Reporting of Wildland-Fire Information (IRWIN) and National Interagency Fire Center (NIFC)



▸ Breakdown by specific causes ▸ Yearly human-caused share of known cause fires

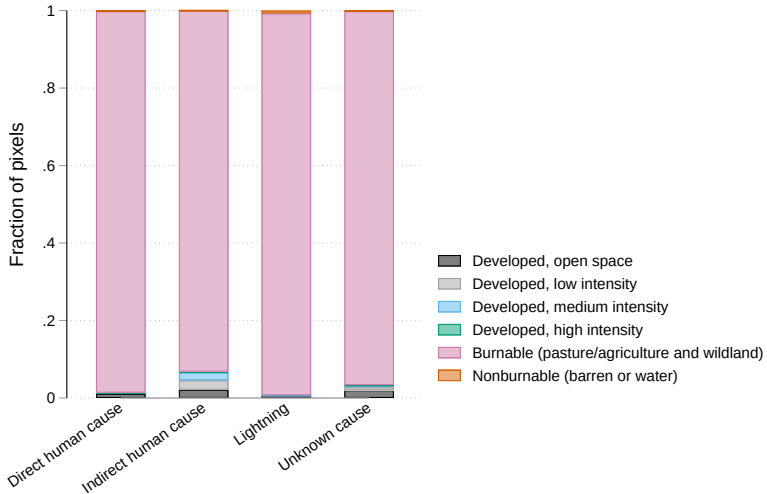
Human-caused fires were larger, on average

Calculated using IRWIN and NIFC



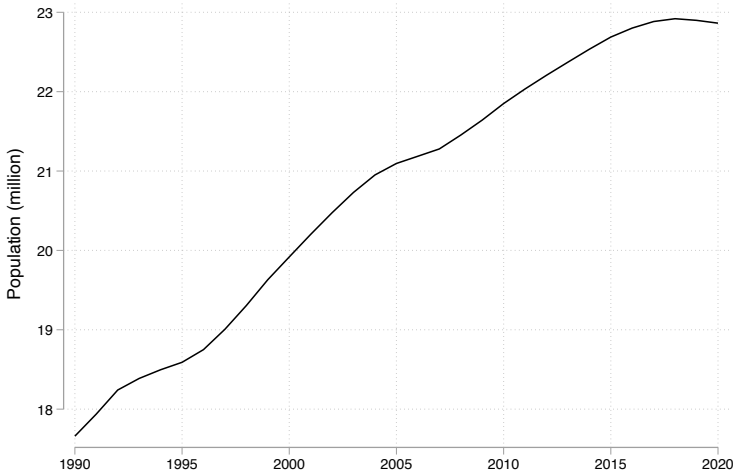
- Total area burned by human-caused fires was also larger

Human-caused fires (direct and indirect) were more likely to burn in developed areas

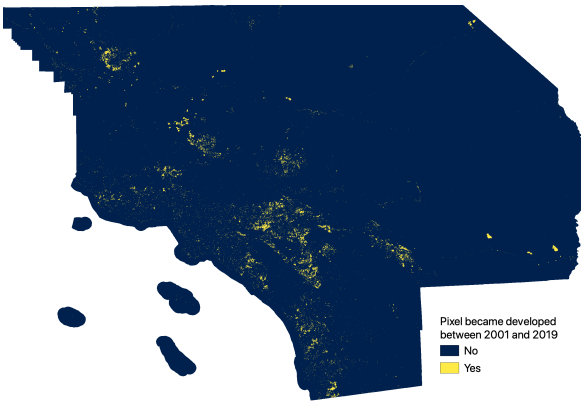


Urban sprawl and fire risk

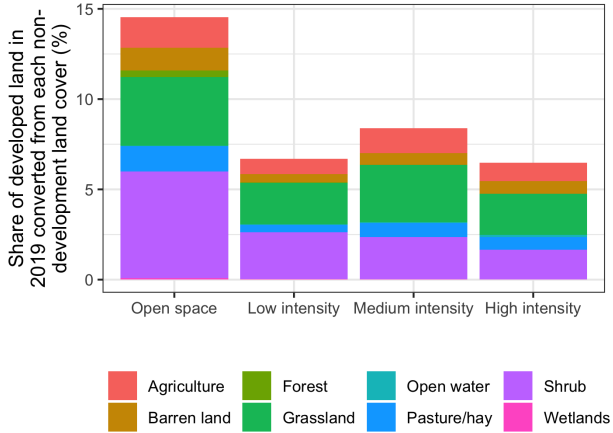
Population in Southern California grew by 3M between 2000-2020



Urban expansion took place in spite of geographic barriers

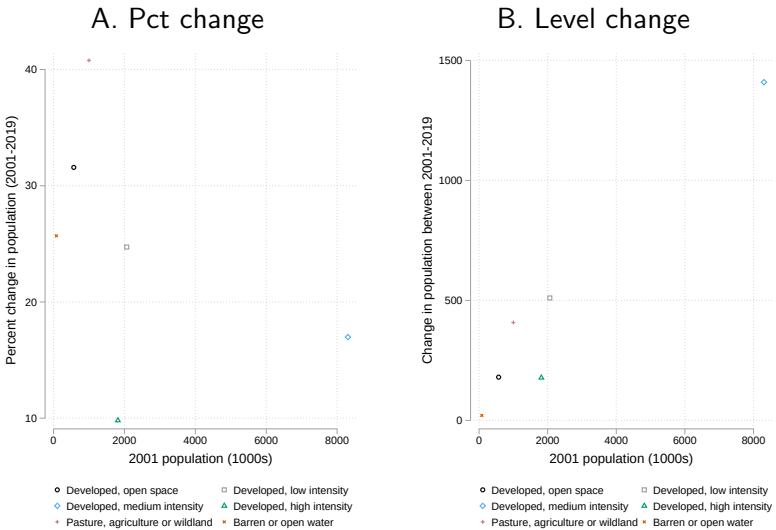


Newly developed points were originally grassland, shrub and agricultural/pasture land in 2001

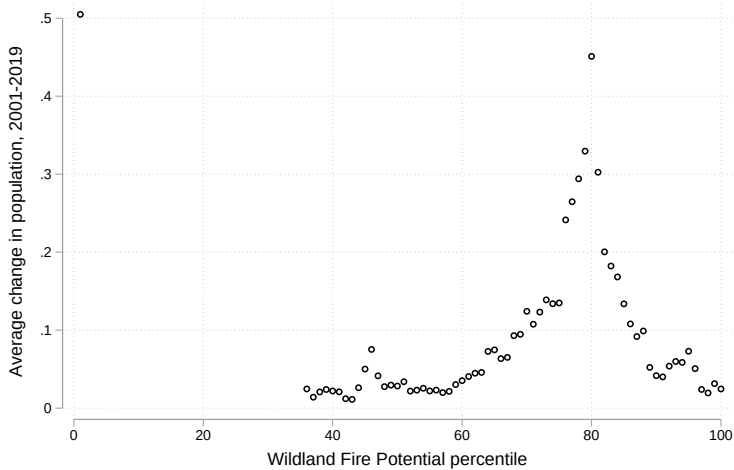


▸ Share of each land cover that was developed ▸ Land cover transition matrix

Wildland and low intensity developments grew faster than other landcover types



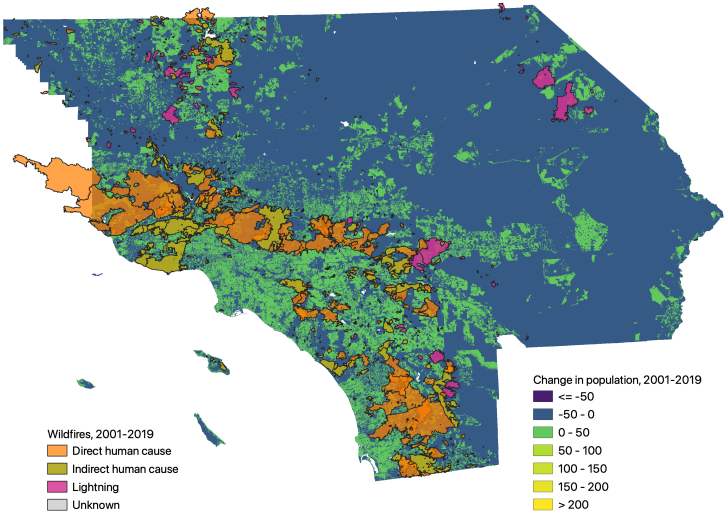
Average population change by fire risk



▸ Aggregate population change ▸ Average population growth

Regression results (preliminary)

Wildfires partially coincide with areas of population growth



Identification

- Regressions of the form

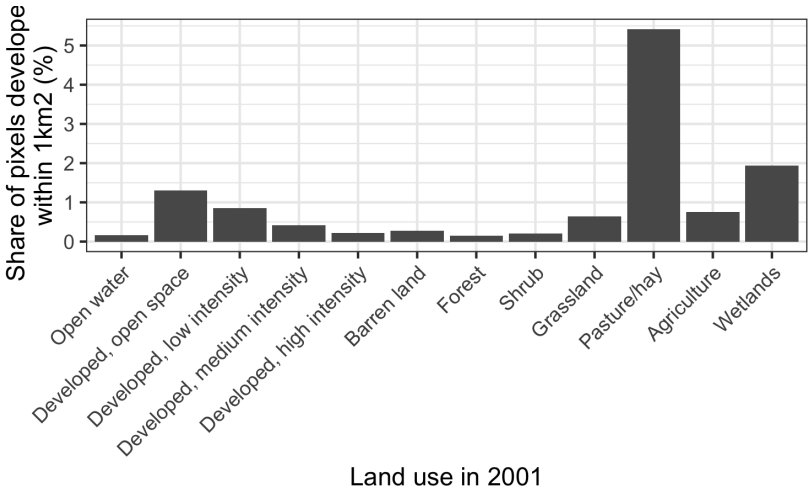
$$P(fire)_i = \alpha + \beta\, Dpop_i + X_i'\gamma + \varepsilon_i$$

  where X_i includes pixel-level environmental and geographic conditions

- Identification relies on
  - $\mathbb{E}[Dpop_i \varepsilon_i | X_i] = 0 \rightarrow$ might be reasonable if X fully captures all amenities and people don't account for unobserved (to me) idiosyncratic fire risk
    - Champ, Donovan and Barth (2013) suggest households do not account for fire risk when choosing where to live
  - Independence of treatment units $\rightarrow$ *definitely violated*

Everything I'll show today suffers from the SUTVA violation...

- Evidence that not just own land cover, but also neighboring land cover might matter



Sample: all pixels

	(1) Any fire	(2) Lightning	(3) Direct human cause	(4) Indirect human cause
Developed (2001)	-10.097***	1.560***	-7.856***	-0.880***
	(0.047)	(0.012)	(0.035)	(0.012)
Developed between 2001-2019	-4.218***	-0.697***	-2.749***	-0.195***
	(0.045)	(0.009)	(0.031)	(0.013)
Prob(moderate drought)	2.425***	0.254***	1.133***	0.206***
	(0.017)	(0.007)	(0.012)	(0.003)
Prob(Severe drought)	8.537***	-4.923***	10.152***	1.002***
	(0.059)	(0.026)	(0.046)	(0.015)
Low WFP	2.948***	0.672***	1.655***	0.235***
	(0.017)	(0.008)	(0.012)	(0.005)
Moderate WFP	7.311***	2.332***	3.598***	0.781***
	(0.028)	(0.015)	(0.020)	(0.009)
High WFP	8.670***	1.127***	4.946***	0.372***
	(0.029)	(0.010)	(0.023)	(0.006)
Very high WFP	3.778***	1.079***	1.516***	0.001
	(0.024)	(0.010)	(0.018)	(0.004)
Barren (2001)	-7.368***	1.516***	-5.867***	-0.742***
	(0.037)	(0.010)	(0.027)	(0.009)
Forest (2001)	-1.490***	1.417***	1.183***	-0.857***
	(0.062)	(0.019)	(0.053)	(0.013)
Shrub (2001)	-6.558***	1.364***	-5.230***	-0.643***
	(0.035)	(0.009)	(0.026)	(0.009)
Grassland (2001)	-3.881***	2.957***	-4.751***	-0.673***
	(0.044)	(0.018)	(0.030)	(0.011)
Pasture/hay (2001)	-9.353***	1.270***	-7.301***	-0.887***
	(0.058)	(0.012)	(0.037)	(0.018)
Agricultural land (2001)	-6.973***	1.242***	-5.391***	-0.698***
	(0.036)	(0.010)	(0.026)	(0.009)
Wetlands (2001)	-6.218***	1.114***	-4.753***	-0.470***
	(0.112)	(0.026)	(0.091)	(0.033)
Developed between 2001-2019			0.000	

Sample: pixels not developed in 2001

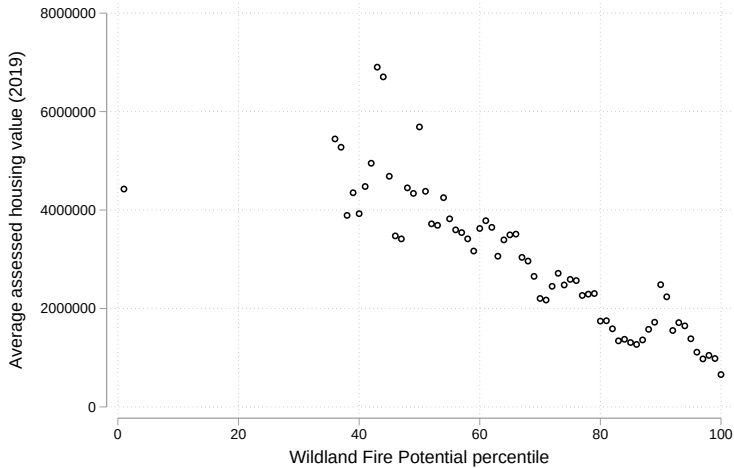
	(1) Any fire	(2) Lightning	(3) Direct human cause	(4) Indirect human cause
Developed between 2001-2019	-4.251***	-0.766***	-2.708***	-0.205***
	(0.043)	(0.008)	(0.026)	(0.013)
Prob(moderate drought)	2.488***	0.177***	1.227***	0.222***
	(0.018)	(0.007)	(0.013)	(0.003)
Prob(Severe drought)	9.323***	-5.401***	11.185***	1.011***
	(0.063)	(0.028)	(0.049)	(0.016)
Low WFP	3.120***	0.745***	1.749***	0.231***
	(0.017)	(0.009)	(0.012)	(0.005)
Moderate WFP	7.830***	2.601***	3.814***	0.792***
	(0.031)	(0.017)	(0.022)	(0.010)
High WFP	9.036***	1.300***	5.072***	0.375***
	(0.031)	(0.011)	(0.024)	(0.007)
Very high WFP	3.875***	1.225***	1.471***	-0.003
	(0.025)	(0.011)	(0.018)	(0.004)
Barren (2001)	-7.789***	1.823***	-6.429***	-0.772***
	(0.040)	(0.011)	(0.030)	(0.010)
Forest (2001)	-2.166***	1.608***	0.524***	-0.894***
	(0.064)	(0.019)	(0.054)	(0.014)
Shrub (2001)	-7.072***	1.617***	-5.818***	-0.675***
	(0.039)	(0.010)	(0.029)	(0.010)
Grassland (2001)	-4.492***	3.166***	-5.381***	-0.707***
	(0.047)	(0.019)	(0.033)	(0.012)
Pasture/hay (2001)	-9.947***	1.585***	-8.006***	-0.923***
	(0.061)	(0.013)	(0.040)	(0.019)
Agricultural land (2001)	-7.356***	1.532***	-5.907***	-0.728***
	(0.039)	(0.011)	(0.029)	(0.010)
Wetlands (2001)	-6.856***	1.365***	-5.434***	-0.507***
	(0.114)	(0.027)	(0.092)	(0.034)
Constant	-134.129***	-9.156***	-66.527***	-12.003***
	(0.959)	(0.386)	(0.692)	(0.164)
N	11391214	11391214	11391214	11391214

Sample: pixels not developed in 2001

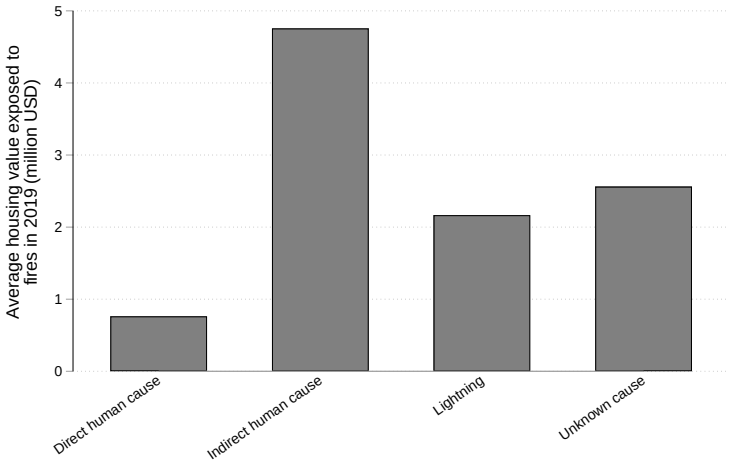
	(1) Any fire	(2) Lightning	(3) Direct human cause	(4) Indirect human cause
Change in population between 2001-2019	-0.409***	-0.044***	-0.241***	-0.026***
	(0.008)	(0.001)	(0.005)	(0.001)
Change in population, squared	0.001***	0.000***	0.001***	0.000***
	(0.000)	(0.000)	(0.000)	(0.000)
Prob(moderate drought)	3.489***	-0.065***	2.047***	0.324***
	(0.022)	(0.008)	(0.015)	(0.004)
Prob(Severe drought)	10.059***	-5.636***	11.817***	1.091***
	(0.066)	(0.029)	(0.051)	(0.017)
Low WFP	3.056***	0.760***	1.696***	0.225***
	(0.017)	(0.009)	(0.012)	(0.005)
Moderate WFP	7.630***	2.645***	3.651***	0.772***
	(0.031)	(0.017)	(0.022)	(0.010)
High WFP	8.732***	1.379***	4.817***	0.344***
	(0.031)	(0.012)	(0.024)	(0.007)
Very high WFP	3.569***	1.310***	1.214***	-0.036***
	(0.026)	(0.011)	(0.019)	(0.005)
Barren (2001)	-1.084***	0.506***	-1.110***	-0.103***
	(0.052)	(0.009)	(0.041)	(0.004)
Forest (2001)	4.413***	0.328***	5.740***	-0.239***
	(0.072)	(0.018)	(0.062)	(0.009)
Shrub (2001)	-0.404***	0.314***	-0.531***	-0.011**
	(0.051)	(0.009)	(0.041)	(0.004)
Grassland (2001)	2.158***	1.846***	-0.102**	-0.042***
	(0.056)	(0.016)	(0.044)	(0.007)
Pasture/hay (2001)	-4.101***	0.243***	-3.305***	-0.311***
	(0.066)	(0.011)	(0.046)	(0.015)
Agricultural land (2001)	-0.693***	0.207***	-0.617***	-0.061***
	(0.052)	(0.009)	(0.041)	(0.004)
Wetlands (2001)	-0.182	0.113***	-0.171*	0.140***
	(0.119)	(0.027)	(0.097)	(0.033)
Constant	-196.495***	5.637***	-117.501***	-18.336***
	(1.199)	(0.439)	(0.860)	(0.243)
N	10997122	10997122	10997122	10997122
R-squared	0.061	0.017	0.048	0.005

How does sprawl increase wildfire costs?

For now, consider housing value gradient in 2019



Infrastructure-caused fires in 2019 had higher expected potential damage



Idea: remove houses from newly developed areas

Unfortunately, not ready for today

- Suppose all the housing newly added to high risk areas was moved
- What would be the decrease in the value of housing vulnerable to fires then?

Next steps

Next steps

- Interact population change with fire risk
- Use better measures of home values from ZTRAX transactions dataset
- Consider role of spatial spillovers from one pixel to the next
- Implement spatial covariance matrix
- Measure cost of protecting each home

Appendix

Methodology behind WFP

1. Use Large Fire Simulator (FSim; Finney et al. 2011) to estimate burn probability (BP) and conditional probabilities of fire intensity levels (FILs)
2. Multiply overall burn probability for each flame length to get actual probabilities for each flame length class.
3. Weight the probabilities in each flame length class by the potential hazard they represent and sum them to derive a measure of
4. Create a separate surface of small wildfire potential based on ignition locations for fires smaller than 300 acres
5. Add the large wildfire potential with the small wildfire potential
6. Apply a set of resistance to control weights based on fireline construction rates in different fuel types from 2008, and construct WFP

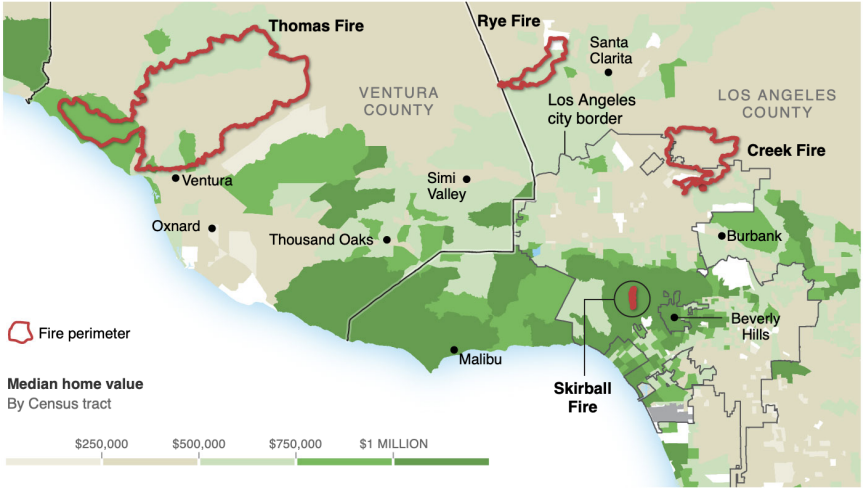
◂ Back to data ◂ Back to map

Drought conditions in California

- D1: Soil is dry; irrigation delivery begins early; active fire season begins, minimal snowpack
- D2: Dryland pasture growth is stunted
- D3: Fire season is longer, with high burn intensity, dry fuels, and large fire spatial extent; more fire crews are on staff
  - River flows decrease; reservoir levels are low and banks are exposed
- D4: Fire season lasts year-round; fires occur in typically wet parts of state; burn bans are implemented
  - Surface water is nearly dry; water theft occurs
  - Wells and aquifer levels decrease; homeowners drill new wells
- D5: Fire season is very costly; number of fires and area burned are extensive
  - Poor air quality affects health
  - Water shortages are widespread; surface water is depleted

◂ Back

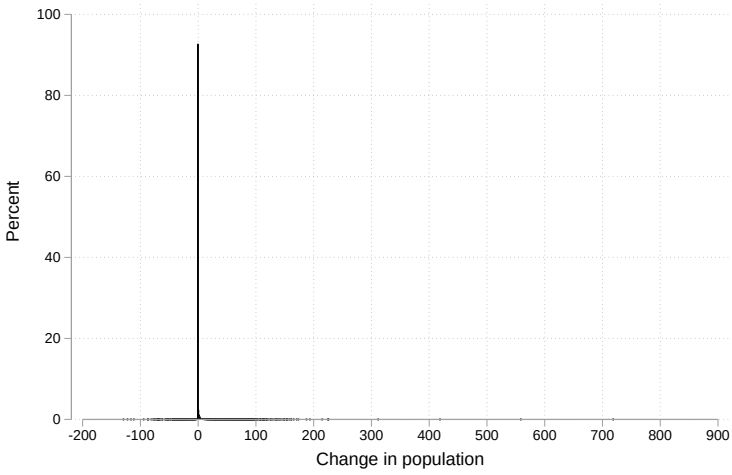
2017 Wildfire perimeters in Grater LA



Sources: U.S. Census Bureau (home value); CAL FIRE (perimeters); Los Angeles Fire Department (Skirball fire preimeter)

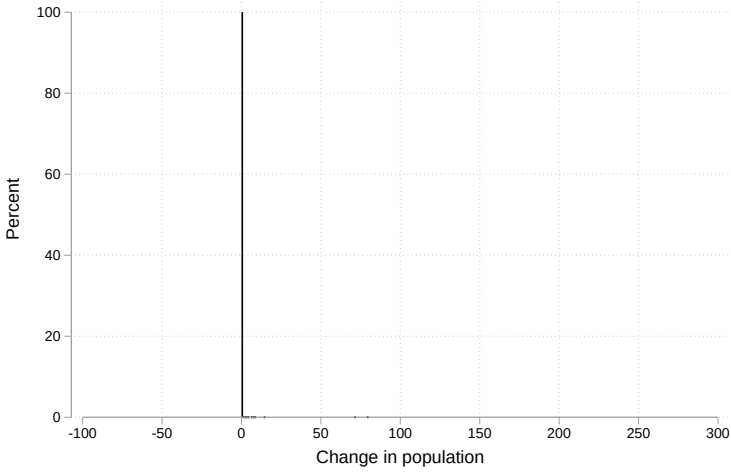
Back

Most pixels did not experience any population change

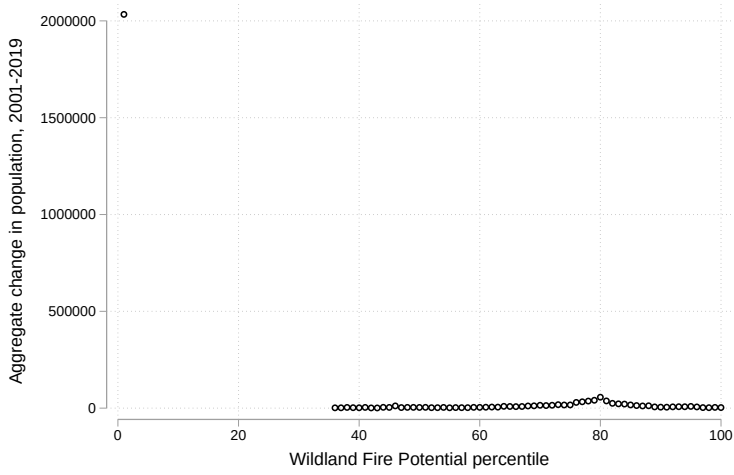


Back

Most empty pixels in 2001 did not experience any population change



Total population change by fire risk



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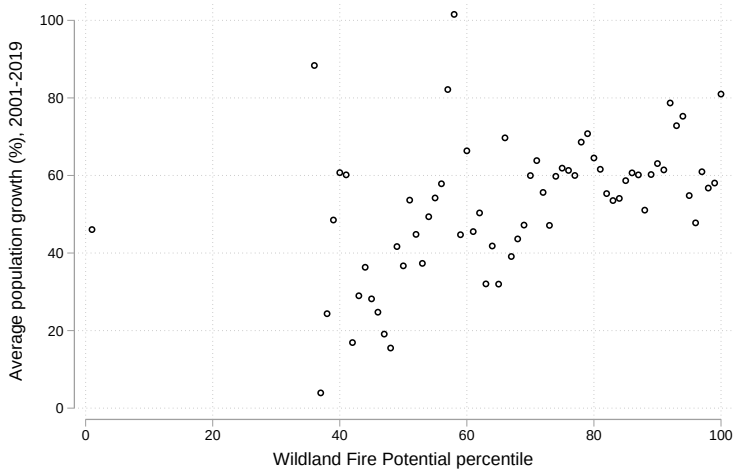
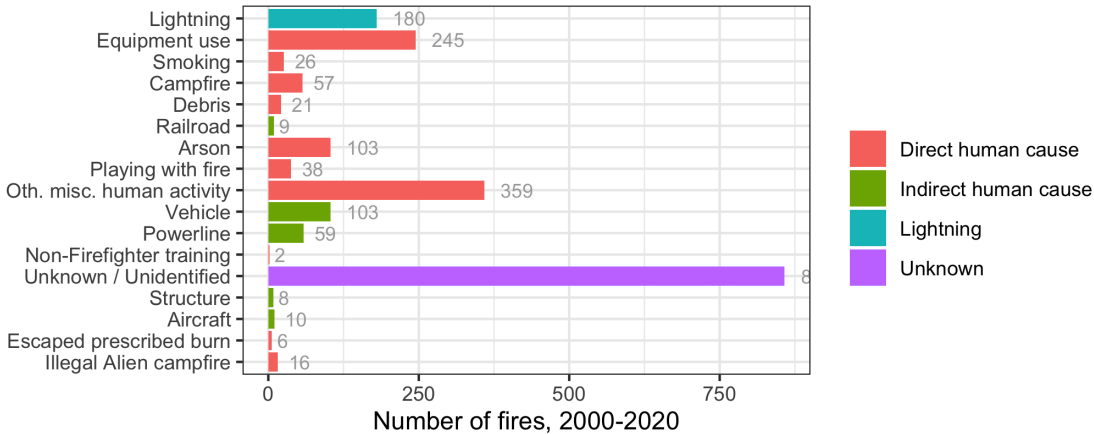
Average population growth by fire risk



◂ Back

Number of wildfires between 2000 and 2020, by cause

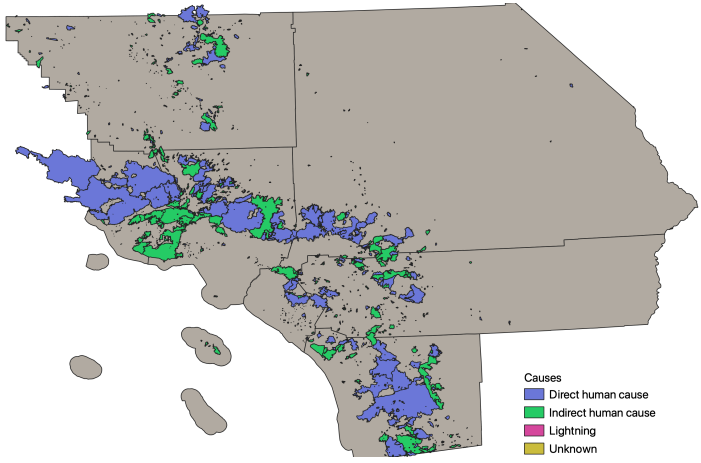
Calculated using data from IRWIN and NIFC



Back

Location of all wildfires between 2000 and 2020, by broad cause

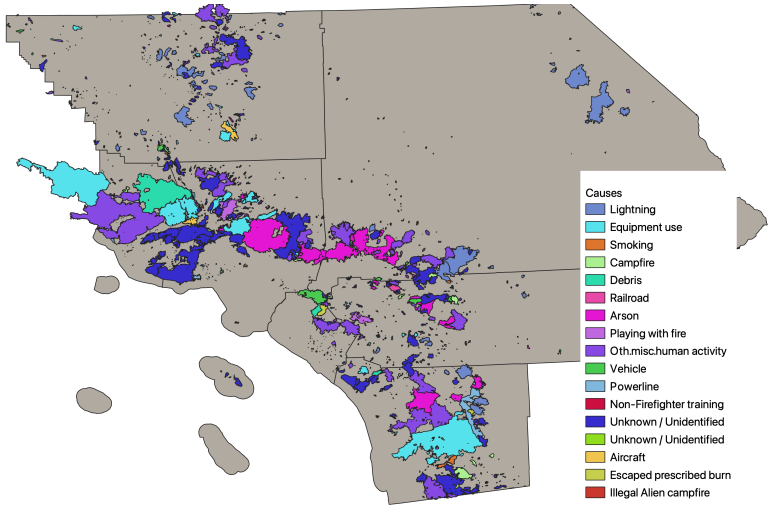
Source: IRWIN and NIFC



◂ Back

Location of all wildfires between 2000 and 2020, by cause

Source: IRWIN and NIFC



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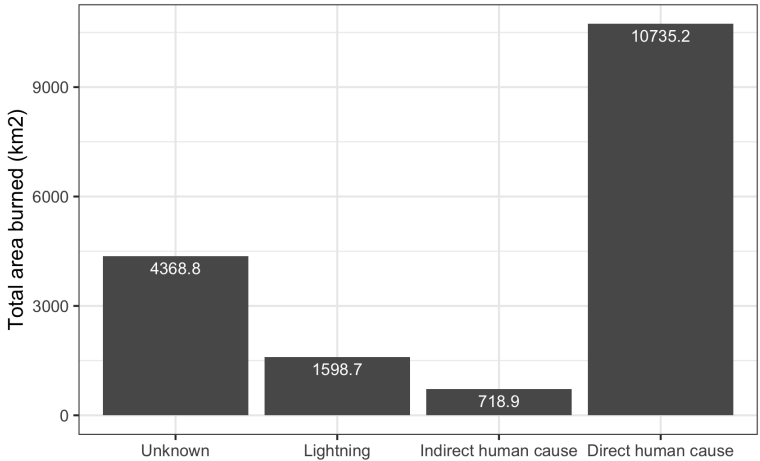
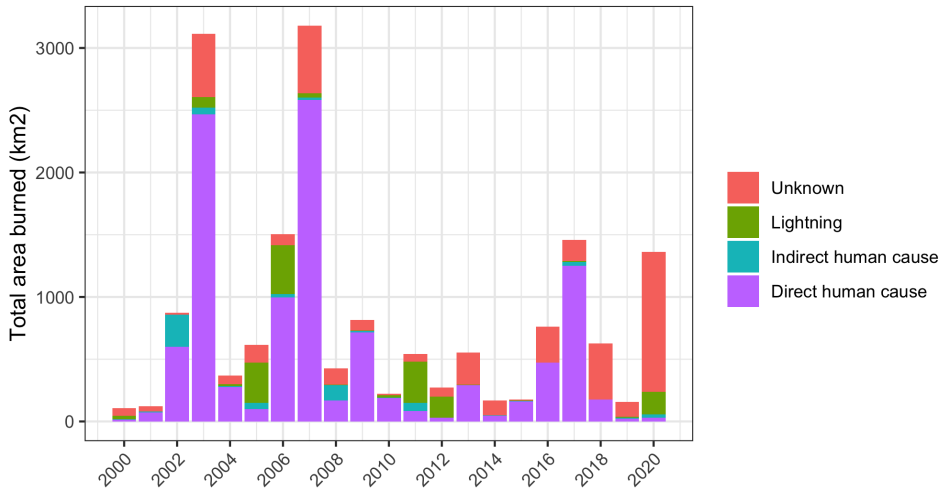
Total area burned by human-caused fires was also larger



Back

Total area burned varies by year, but direct human cause fires still burned a much larger area



Summary statistics, pooled

	Mean	SD	P10	P50	P90
Population (people per pixel)	1.253276	7.559922	0	0	.1494621
Open water	.0335585	.1800898	0	0	0
Developed	.087503	.2825707	0	0	0
Developed, open space	.0203965	.1413524	0	0	0
Developed, low intensity	.0195039	.1382876	0	0	0
Developed, medium intensity	.0370654	.1889221	0	0	0
Developed, high intensity	.0105372	.1021085	0	0	0
Barren	.0727649	.2597503	0	0	0
Forrest	.0334219	.1797357	0	0	0
Shrub	.6063066	.4885682	0	1	1
Grassland	.1122594	.3156853	0	0	1
Pasture/hay	.0037648	.061242	0	0	0
Agriculture	.0461866	.209889	0	0	0
Wetlands	.0042343	.0649335	0	0	0
Experienced drought	.8526948	.3544099	0	1	1
Experienced severe drought	.4331089	.4955054	0	0	1
Observations	99400192				

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Summary statistics, 2001

	Mean	SD	P10	P50	P90
Population (people per pixel)	1.149908	7.092532	0	0	.1488161
Open water	.0335033	.1799467	0	0	0
Developed	.0832039	.2761901	0	0	0
Developed, open space	.0197359	.1390913	0	0	0
Developed, low intensity	.0192714	.1374774	0	0	0
Developed, medium intensity	.0343247	.1820618	0	0	0
Developed, high intensity	.0098719	.0988656	0	0	0
Barren	.0733371	.260689	0	0	0
Forrest	.0392674	.1942306	0	0	0
Shrub	.6150172	.4865913	0	1	1
Grassland	.1013775	.301828	0	0	1
Pasture/hay	.0042347	.0649365	0	0	0
Agriculture	.0457956	.2090415	0	0	0
Wetlands	.0042634	.0651555	0	0	0
Experienced drought	.624218	.4843242	0	1	1
Experienced severe drought	0	0	0	0	0
Observations	12425024				

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Summary statistics, 2019

	Mean	SD	P10	P50	P90
Population (people per pixel)	1.374866	8.102993	0	0	.1627537
Open water	.033631	.1802775	0	0	0
Developed	.0907395	.2872384	0	0	0
Developed, open space	.0208432	.1428592	0	0	0
Developed, low intensity	.0196001	.1386216	0	0	0
Developed, medium intensity	.0391259	.1938944	0	0	0
Developed, high intensity	.0111704	.105098	0	0	0
Barren	.0711525	.2570793	0	0	0
Forrest	.0285576	.1665595	0	0	0
Shrub	.6261981	.483812	0	1	1
Grassland	.0947858	.2929189	0	0	0
Pasture/hay	.0033555	.0578293	0	0	0
Agriculture	.0473284	.2123403	0	0	0
Wetlands	.0042517	.065066	0	0	0
Experienced drought	.970363	.1695839	1	1	1
Experienced severe drought	.2252773	.4177648	0	0	1
Observations	12425024				

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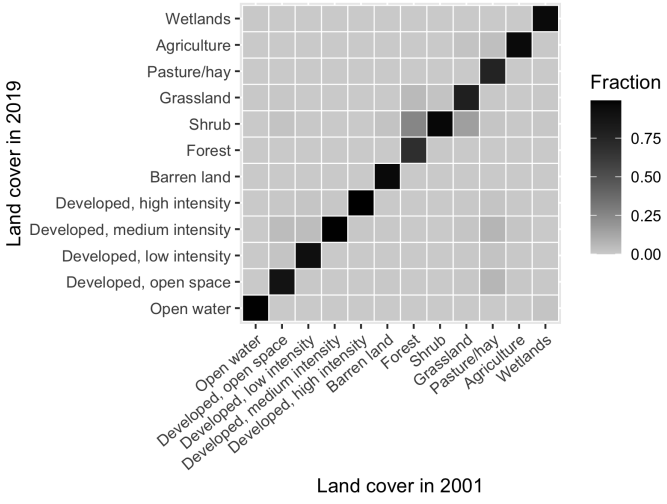
Land cover transition matrix



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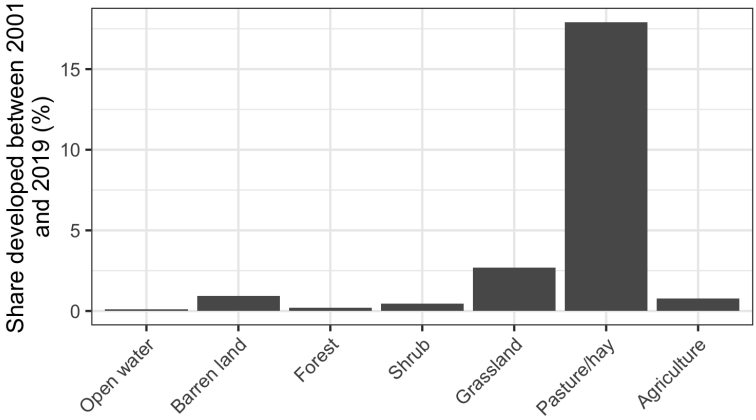
Share of each land cover type that was developed between 2001-2019



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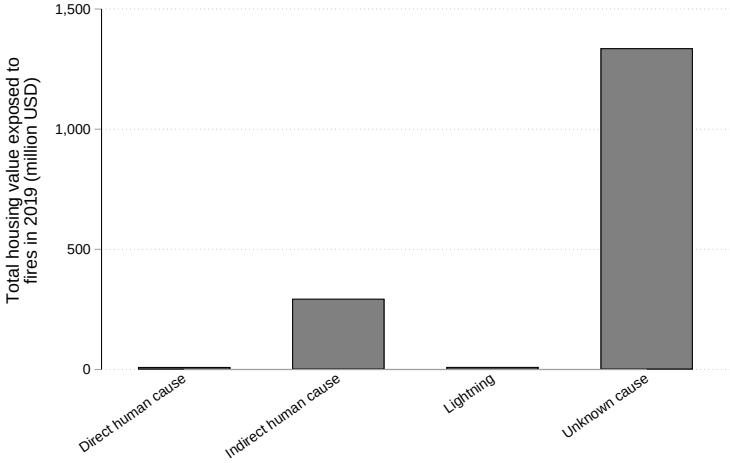
Total housing value exposed to wildfires in 2019



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