QUANTIFYING FIRE BEHAVIOR VERSUS SOCIETAL BENEFITS OF SOUTHERN CALIFORNIA SHRUBLANDS AND GRASSLANDS

Christopher A. Dicus[1]
California Polytechnic State University, Natural Resources Management Department, San Luis Obispo, CA 93407, USA

Maurica A. Zimmerman
California Department of Forestry & Fire Protection, 635 N. Santa Rosa Street, San Luis Obispo, CA 93401, USA

ABSTRACT

Urban sprawl in southern California perpetually threatens native shrublands and grasslands, which intrinsically provide both biophysical and socioeconomic benefits to society. However, these vegetation types are simultaneously prone to high-intensity wildfires that lead to enormous damage to human interests. After the southern California firestorms of October 2003, new regulations were adopted that increased the mandatory vegetation clearance around structures in order to reduce fire risk, which may significantly impact the positive benefits that grasslands and shrublands provide. To address this apparent conflict, we investigated the tradeoffs between societal benefits derived from major shrubland, grassland, and woodland vegetation types in southern California versus the potential fire behavior associated with each vegetation type.

Two state-of-the-art, geographic information system–based software packages were utilized in the analysis, which focused on San Diego County, California. For each of the most common grassland, shrubland, and woodland vegetation communities in the area, FARSITE was utilized to assess potential fire behavior under average and extreme weather conditions. The most extreme fire behavior was found in nonnative grasslands and scrub oak chaparral communities and least extreme in coast live oak (*Quercus agrifolia*) communities. Under Santa Ana wind conditions, simulated fires in almost all vegetation types burned over 3 km into a developed area in $<$1 h. CITYgreen was used to quantify air pollution removal, carbon sequestration, and stormwater retention for each of the vegetation types, but was found to be largely ineffective because it calculated no measurable benefits for any non-tree vegetation types. To ensure sustainable neighborhoods in the wildland–urban interface, diverse stakeholders must create collaborative management plans that simultaneously reduce fire risk and maximize societal benefits.

keywords: chaparral, CITYgreen, FARSITE, fire behavior modeling, grassland, shrubland, southern California, wildland–urban interface.

Citation: Dicus, C.A., and M.A. Zimmerman. 2007. Quantifying fire behavior versus societal benefits of southern California shrublands and grasslands. Pages 214–220 *in* R.E. Masters and K.E.M. Galley (eds.). Proceedings of the 23rd Tall Timers Fire Ecology Conference: Fire in Grassland and Shrubland Ecosystems. Tall Timbers Research Station, Tallahassee, Florida, USA.

INTRODUCTION

In the wildland–urban interface, differing vegetation types provide various levels of tangible and intangible benefits to society. For example, vegetation not only enhances community attractiveness, but also lowers home cooling costs (Taha et al. 1997), reduces air pollution (Taha 1996, Taha et al. 1997) and stormwater runoff (Sanders 1986), and sequesters carbon (Nowak and Rowntree 1991, McPherson et al. 1994). However, vegetation may simultaneously increase the risk to human development because it fuels wildfires. The type and structure of a given vegetation community will inherently influence both the benefits and the risk to a local development.

This seeming paradox in societal benefits versus fire risk of vegetation is readily exemplified in southern California, where a burgeoning population has regularly developed adjacent to and intermixed with highly fire-prone shrubland and grassland communities. The population of San Diego, Los Angeles, Orange, Riverside, San Bernardino, and Ventura counties in southern California in 2000 was 20.5 million and is expected to grow by at least 10% over the next 10 y (data from U.S. Census Bureau), which will continue to cause an enormous conversion of native vegetation to developed areas. For example, from 1985 to 2002, the city of San Diego experienced a 39% increase in urban areas across the landscape, which led to a 32% loss of grasslands, 7% loss of shrublands, and 27% of loss of tree cover (American Forests 2003).

While the region's shrubland, grassland, and woodland communities provide numerous benefits, they are also prone to high-intensity, destructive wildfires. For example, the 2003 Cedar Fire in San Diego County, the largest and most destructive fire in California's history, burned across 273,246 acres, killed 24 people, and destroyed 4,847 structures (California Department of Forestry & Fire Protection 2004). As a result of the 2003 Fire Siege, California Senate Bill 1369 was signed into law in 2004, which amended Public Resources Code 4291 to increase mandatory vegetation clearance around homes from a previous standard of 9.14 m (30 ft) to a current standard of

[1] Corresponding author (cdicus@calpoly.edu).

Table 1. Holland (1986) and CITYgreen software classifications of major vegetation communities in San Diego County, California.

Holland vegetation classification	Holland description	CITYgreen classification
42110–Foothill Grassland	Perennial purple tussockgrass (*Nassella pulchra*) or needlegrass (*Stipa* spp.) to 0.6 m with interspersed annuals	Pasture/Range (continuous forage for grazing): ground cover >75%
42200–Non-native Grassland	Dense annual grasses with flowering culms to 1 m	Pasture/Range (continuous forage for grazing): ground cover >75%
37900–Scrub Oak Chaparral	Dense scrub oak (*Quercus berberidifolia*), coastal sage scrub oak (*Q. dumosa*), birchleaf mountain mahogany (*Cercocarpus montanus* var. *glaber*) to 6 m	Shrub: ground cover >75%
71160–Coast Live Oak Woodland	Coast live oak (*Quercus agrifolia*) 10–25 m with understory toyon (*Heteromeles arbutifolia*), currants (*Ribes* spp.), laurel sumac (*Malosma laurina*), or blue elderberry (*Sambucus nigra* ssp. *canadensis*)	Trees: forest litter understory: no grazing, forest litter and brush adequately cover soil
37200–Chamise Chaparral	Chamise (*Adenostoma fasciculatum*) to 3 m with little herbaceous understory	Arid & Semi-Arid Rangeland: desert shrub: ground cover between 40% and 70%
37120–Southern Mixed Chaparral	Coastal sage scrub oak, chamise, manzanita (*Arctostaphylos* spp.), ceanothus (*Ceanothus* spp.) 1.5–3 m with little understory	Arid & Semi-Arid Rangeland: desert shrub: ground cover >70%
32501–Diegan Coastal Sage Scrub	California sagebrush (*Artemisia californica*), California buckwheat (*Eriogonum fasciculatum*), white sage (*Salvia apiana*)	Arid & Semi-Arid Rangeland: sagebrush: ground cover between 40% and 70%

30.48 m (100 ft) in all designated areas where the state has the primary suppression responsibilities. These new standards have the potential to significantly reduce the losses caused by wildfire, but will also likely reduce the many tangible benefits to society that the vegetation provides.

To assist decision-making by land managers in the wildland–urban interface of southern California, we utilized two widely used geographic information system (GIS)–based applications to explore the tradeoffs in quantifiable benefits to society versus the inherent fire risk of major shrubland, grassland, and woodland community types in San Diego County. Our major objectives were to 1) quantify wildfire rate of spread, flame length, and fireline intensity under both average and extreme weather conditions for 7 major shrubland, grassland, and woodland community types that are common in San Diego County; 2) quantify stormwater runoff removal, air pollution reduction, and carbon sequestration for each of those same vegetation types; and 3) evaluate each of the major vegetation types for minimization of fire behavior and maximization of societal benefits.

METHODS

Our analysis employed FARSITE 4.1.03 (USDA Forest Service Fire Sciences Laboratory, Missoula, MT) for fire behavior simulations and CITYgreen for ArcGIS (American Forests, Washington, D.C.) for calculation of societal benefits. GIS layers necessary for the analysis were obtained from the San Diego Association of Governments and included a 10-m digital elevation model (DEM) and a vegetation classification shape file. Those layers were converted into forms required by FARSITE and by CITYgreen with the Spatial Analyst extension in ArcMap 9.2. FARSITE required ASCII data for elevation, slope, aspect, fuel model, and canopy coverage. The Spatial Analyst extension of ArcMap derived the slope and aspect grids from the DEM and then used the DEM as a background basis for deriving the fuel model grid from the vegetation shape file. The ArcToolbox functions in ArcMap were then used to create ASCII files from these raster data sets. For CITYgreen analysis, the vegetation shape file was converted to a grid with Spatial Analyst.

Vegetation communities in San Diego County were classified per Holland (1986) and categorized by CITYgreen protocol to calculate societal benefits (Table 1). Each vegetation community had previously been assigned a standard or custom fire behavior fuel model for pre-fire planning purposes in the San Diego area (M. Scott, Rancho Santa Fe Fire District, personal communication); these fuel model designations were used in the present study. Using ArcMap 9.2, we determined the most prevalent shrubland, grassland, and woodland fuel models in San Diego County to be standard fuel models 1, 3, 4, and 9 (Anderson 1982), and southern California custom fuel models SCAL15, SCAL17, and SCAL18 (see BehavePlus 3.0.2 for specific values associated with southern California custom fuel models). Within each of those fuel models, the most prevalent vegetation community, by area, was selected to represent vegetation classification per CITYgreen protocol. For a given CITYgreen analysis, all vegetation across the landscape was converted to a single type.

A ‘‘typical’’ area in San Diego County was then sought in which to analyze potential fire behavior and societal benefits for each of the pertinent vegetation communities. The Scripps Ranch (32°54.134′N, 117°05.985′W), a housing community in the wildland–urban interface of inland San Diego County, was chosen for the analysis because it had the majority of pertinent vegetation communities in or near the vicinity and also had 322 homes that were consumed during the 2003 Cedar Fire. A subsection of land adjacent to

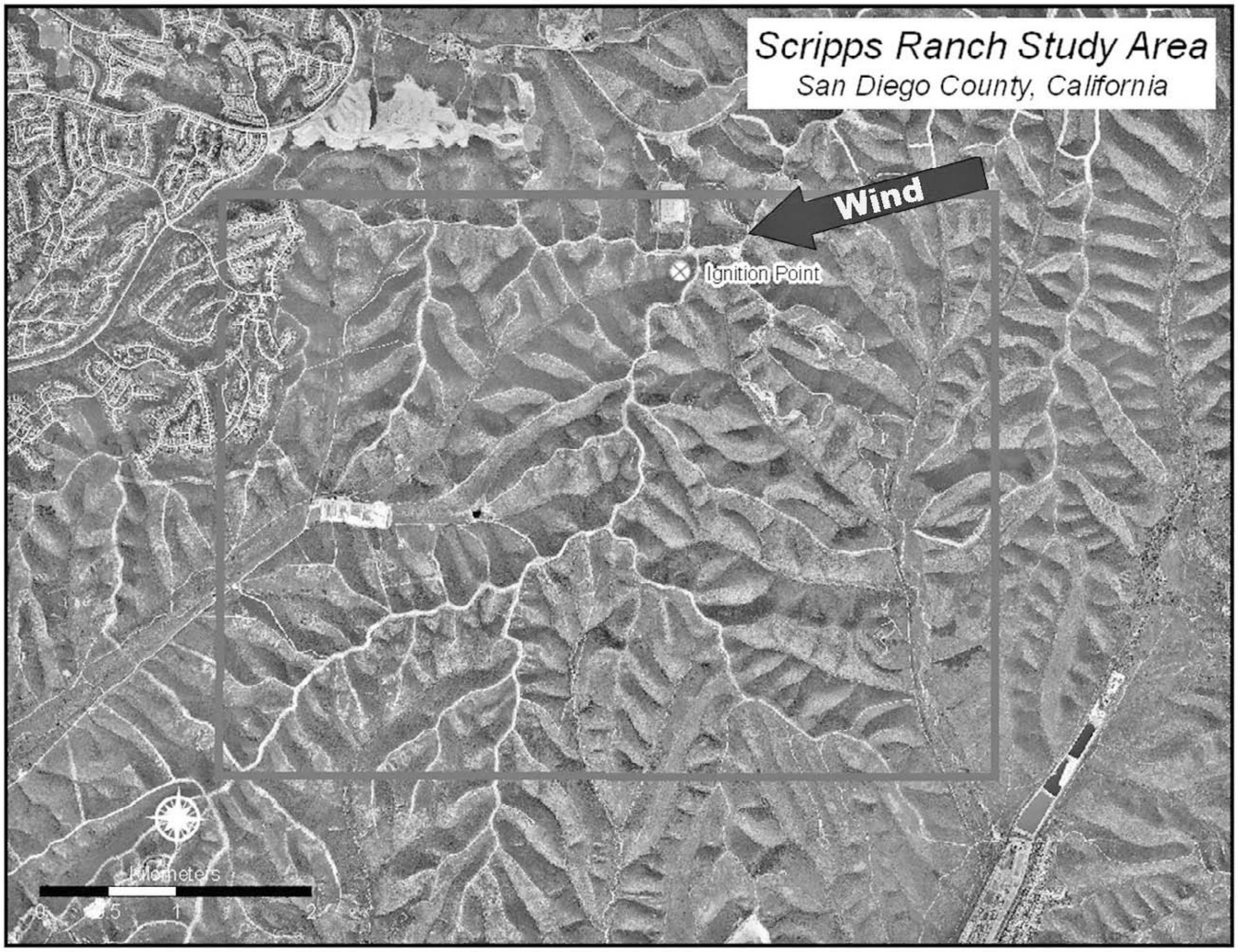

Fig. 1. Aerial photograph of the Scripps Ranch study area, San Diego County, California. Outline designates the area in which societal benefits of vegetation communities were calculated by CITYgreen software. The ignition point represents a potential location for a human-caused ignition. The arrow shows the characteristic direction of local Santa Ana winds. Photo taken in 2005 by AirPhotoUSA.

and including a small portion of the Scripps Ranch (7,742 ha) was utilized in the analysis (Figure 1). For fire-simulation purposes, a single potential ignition point was designated at the junction of two major secondary roads, which, due to relative ease of access, was meant to reflect a likely location for a human-caused ignition.

Table 2. Average and extreme weather and fuel moistures during September–October for FARSITE fire behavior simulation in San Diego County, California.

	Percentile	
Weather parameter[a]	Average 50%	Extreme 97%
High temperature (°C)	28.3	37.8
Relative humidity (%)	45	12
Wind speed (km/h)	12.9	64.4[b]
Fuel moisture (%)		
1-h fuels	7	3
10-h fuels	9	4
100-h fuels	16	11
Live herbaceous fuels	93	5
Live woody fuels	1	1

[a] Data from Poway RAWS, San Diego, California, September–October, 1981–1997.
[b] Winds changed from calculated 21 km/h to reflect Santa Ana conditions.

Weather data required for FARSITE analysis was calculated by FireFamilyPlus 3.0.5 (Systems for Environmental Management and USDA Forest Service Fire Sciences Laboratory, Missoula, MT) with historic weather data (1981–1997) from the nearby Poway RAWS (Remote Automated Weather Station). Pertinent weather and fuel moisture data (high temperature, minimum relative humidity, wind speed, as well as 1-h, 10-h, 100-h, live herbaceous, and live woody fuel moistures) were calculated for average (50^{th} percentile) and extreme (97^{th} percentile) fire weather during the months of September and October, the two months that have historically burned most frequently in the area (Table 2). For each FARSITE simulation, temperature and relative humidity were kept constant throughout the day. Winds were also held constant throughout the day for both weather percentiles and were from north 67° east (characteristic direction of local Santa Ana winds); however, because calculated 97^{th} percentile winds did not accurately reflect the most extreme fire conditions, namely Santa Ana winds, 97^{th} percentile

Table 3. FARSITE mean fire behavior outputs under various weather scenarios for major vegetation communities (Holland 1986) in San Diego County, California.

Fuel model	Holland vegetation classification	Treatment		Fire behavior output				
		Weather (%)	Wind (%)	Rate of spread (m/min)	Flame length (m)	Fireline intensity (kW/m)	Area (ha)	Perimeter (km)
1	Foothill Grassland	50	50	5.9 (0.02)[a]	0.6 (0.020)	92.1 (0.29)	501.4	10.1
		97	50	9.1 (0.02)	0.8 (0.001)	182.3 (0.32)	508.4	10.2
		97	97	23.6 (0.06)	1.2 (0.001)	489.3 (1.29)	1,981.2	38.7
3	Non-native Grassland	50	50	13.8 (0.02)	2.4 (0.001)	1,850.7 (2.19)	2,268.0	41.6
		97	50	20.3 (0.02)	3.2 (0.002)	3,535.5 (3.12)	2,300.5	43.0
		97	97	25.2 (1.29)	3.6 (0.009)	5,138.2 (20.70)	1,673.8	31.9
4	Scrub Oak Chaparral	50	50	10.5 (0.02)	3.8 (0.003)	4,976.0 (8.07)	822.0	17.3
		97	50	13.5 (0.17)	4.6 (0.003)	7,638.8 (10.17)	960.3	19.6
		97	97	19.3 (0.09)	5.3 (0.013)	11,791.0 (50.4)	1,252.4	27.7
9	Coast Live Oak Woodland	50	50	0.7 (0.001)	0.4 (0.003)	45.9 (0.61)	7.7	1.0
		97	50	1.0 (0.010)	0.6 (0.003)	92.5 (0.86)	7.8	1.0
		97	97	6.8 (0.03)	1.4 (0.003)	588.7 (2.38)	189.1	6.0
15	Chamise Chaparral	50	50	2.3 (0.01)	1.4 (0.005)	605.3 (3.90)	46.8	2.5
		97	50	4.7 (0.02)	2.2 (0.004)	1,585.3 (5.14)	121.9	4.4
		97	97	8.7 (0.04)	2.7 (0.006)	2,958.6 (14.32)	388.4	15.1
16	Southern Mixed-Chaparral	50	50	2.9 (0.02)	1.6 (0.006)	787 (5.5)	100.7	3.9
		97	50	11.2 (0.02)	3.7 (0.003)	4,871.7 (7.50)	685.7	13.3
		97	97	13.3 (0.06)	4.1 (0.013)	6,391.7 (29.84)	801.8	20.3
18	Diegan Coastal Sage Scrub	50	50	4.3 (0.01)	2.8 (0.005)	2,564.0 (9.0)	160.3	5.1
		97	50	7.8 (0.02)	4.1 (0.004)	5,955.7 (11.7)	331.8	7.7
		97	97	9.8 (0.05)	4.3 (0.012)	7,882.9 (37.4)	528.0	16.4

[a] Parenthetical values represent the standard error of means.

winds were changed from the calculated 21 km/h to a more reflective 65 km/h. Fuel moistures for both weather percentiles were input into a required fuel moisture file in a FARSITE project.

Fires were simulated for multiple combinations of fuel models and weather scenarios. For a given simulation, vegetation across the landscape was converted to the single fuel model of interest; nonburnable models remained nonburnable. Each landscape of a single fuel model was then simulated under three separate weather scenarios, including 1) 50th percentile weather, 50th percentile winds (average conditions); 2) 97th percentile weather, 50th percentile winds (extreme temperature, relative humidity, and fuel moisture without Santa Ana winds); and 3) 97th percentile weather, 97th percentile winds (extreme temperature, relative humidity, fuel moisture, as well as Santa Ana winds). Simulation parameters were as follows: Time Step = 30.0 min, Visible Time Step = 1.0 h, Perimeter Resolution = 30 m, Distance Resolution = 30 m. The conditioning period for fuel moistures was 1 d. Fires were simulated for 3 h, which allowed adequate demonstration of fire spread across the landscape while confining fire boundaries to the study area (during non–Santa Ana conditions). Output ASCII raster files of rate of spread, flame length, and fireline intensity were created for each simulation. After deleting all nonburned observations in the output ASCII raster layers, a general linear models procedure was conducted in the SAS System for Windows 8.02 (SAS Institute, Cary, NC) to test significance between fuel models for each of the three weather scenarios.

RESULTS

All fire behavior parameters varied significantly between vegetation types for each of the three weather scenarios (all $P < 0.001$) (Table 3). The fastest rate of spread was in the nonnative grass community, followed by scrub oak chaparral, Diegan coastal sage scrub, and foothill grass communities. The highest flame lengths and fireline intensities were observed in the scrub oak chaparral, followed by the Diegan coastal sage scrub and the nonnative grass communities. Southern mixed-chaparral demonstrated the greatest range in variation in simulated fire behavior between weather scenarios.

Under normal weather conditions, only fires in the nonnative grasslands and scrub oak chaparral reached the homes within 3 h (Figure 2). As expected, fire behavior increased dramatically during extreme weather, particularly when the Santa Ana winds were simulated. Under Santa Ana conditions, the simulated fires arrived at the subdivision within 1 h in all vegetation types except for the coast live oak (*Quercus agrifolia*) type (Figure 3). It should be noted, however, that differences in flame length between vegetation types could potentially affect the survivability of the homes, based on construction techniques and materials.

Because the simulated fires extended beyond the project area during Santa Ana conditions in all vegetation communities except coast live oak (Figure 3), the calculated areas and perimeters in those communities were underestimated. Indeed, the fire simulated during Santa Ana conditions in nonnative grassland actually burned less area than during less extreme conditions (Table 3) because of a wind-induced increase in the fire's length-to-width ratio and a boundary that extended beyond the project area (Figure 3).

Only the coast live oak vegetation type showed any tangible societal benefits. In the coast live oak scenario, CITYgreen calculated that the trees removed

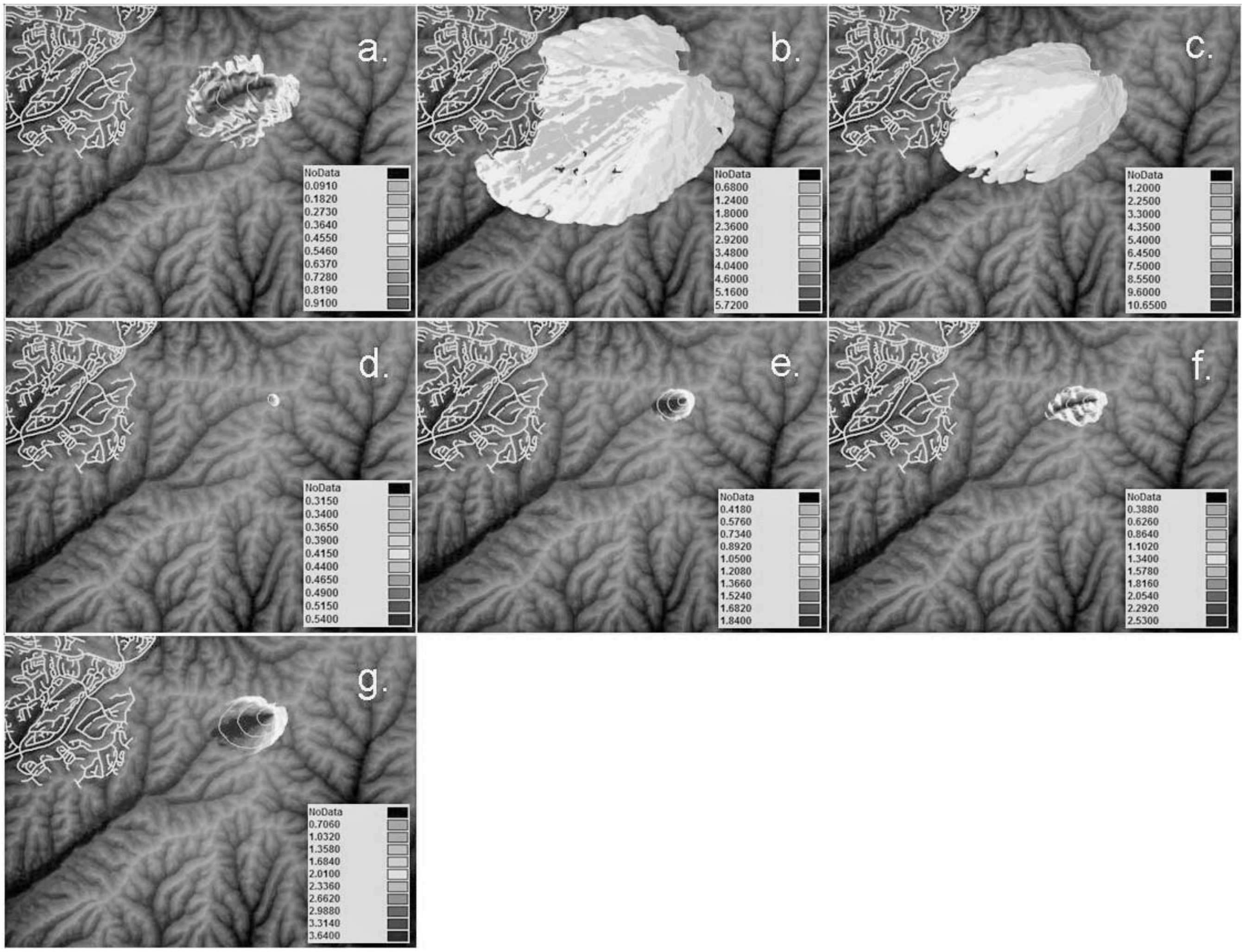

Fig. 2. Simulated fire spread for 3 h under 50th percentile historic weather conditions (September–October) in (a) foothill grasses, (b) nonnative grasses, (c) scrub oak chaparral, (d) coast live oak, (e) chamise chaparral, (f) southern mixed-chaparral, and (g) Diegan coastal sage scrub community types in San Diego County, California.

100.6 kg/ha of air pollution, sequestered 93,387 kg/ha of carbon, and reduced stormwater runoff by 40.4 m^3/ha. For all grassland and shrubland vegetation types, CITYgreen calculated zero benefits.

DISCUSSION

Based on past fires in the region, estimated flame lengths (Table 3) may be low, especially under Santa Ana conditions. Even though fires in most vegetation types reached the subdivision within 3 h, not all fires would necessarily result in loss of homes. For example, because of the relatively lower flame lengths in the foothill grassland community, if the homes had proper noncombustible siding materials, they would likely survive direct frontal impingement of the fire, even under Santa Ana conditions. However, it must be noted that not all homes in a wildland fire are consumed by direct flame contact. Many structures are ignited via lofted embers, which land either on combustible roofs and decks or enter through exposed vents or windows (Cohen 2000). Thus, burning embers from a fire in the coast live oak vegetation type could potentially ignite homes even though the fire never reaches the subdivision. Further, some homes could have tremendous clearance and be built with flame-resistant construction materials, yet still be at high risk because of location in a topographically susceptible area such as the top of a slope or in a chimney. Thus, pre-fire management in the wildland–urban interface must not solely be based on the reduction of fuels, but also must contain elements of home construction, home placement, and landscaping, such that homes can withstand a wildfire in the absence of any suppression actions, which occurred in the early, chaotic stages of the 2003 Fire Siege.

Of note, one of the more explosive vegetation communities in terms of both rate of spread and fire intensity was the nonnative grass community, which should therefore be largely avoided adjacent to human development. However, an increasing population regularly leads to more potential ignition sources and subsequently greater fire frequency, which has been shown to cause a conversion away from native chap-

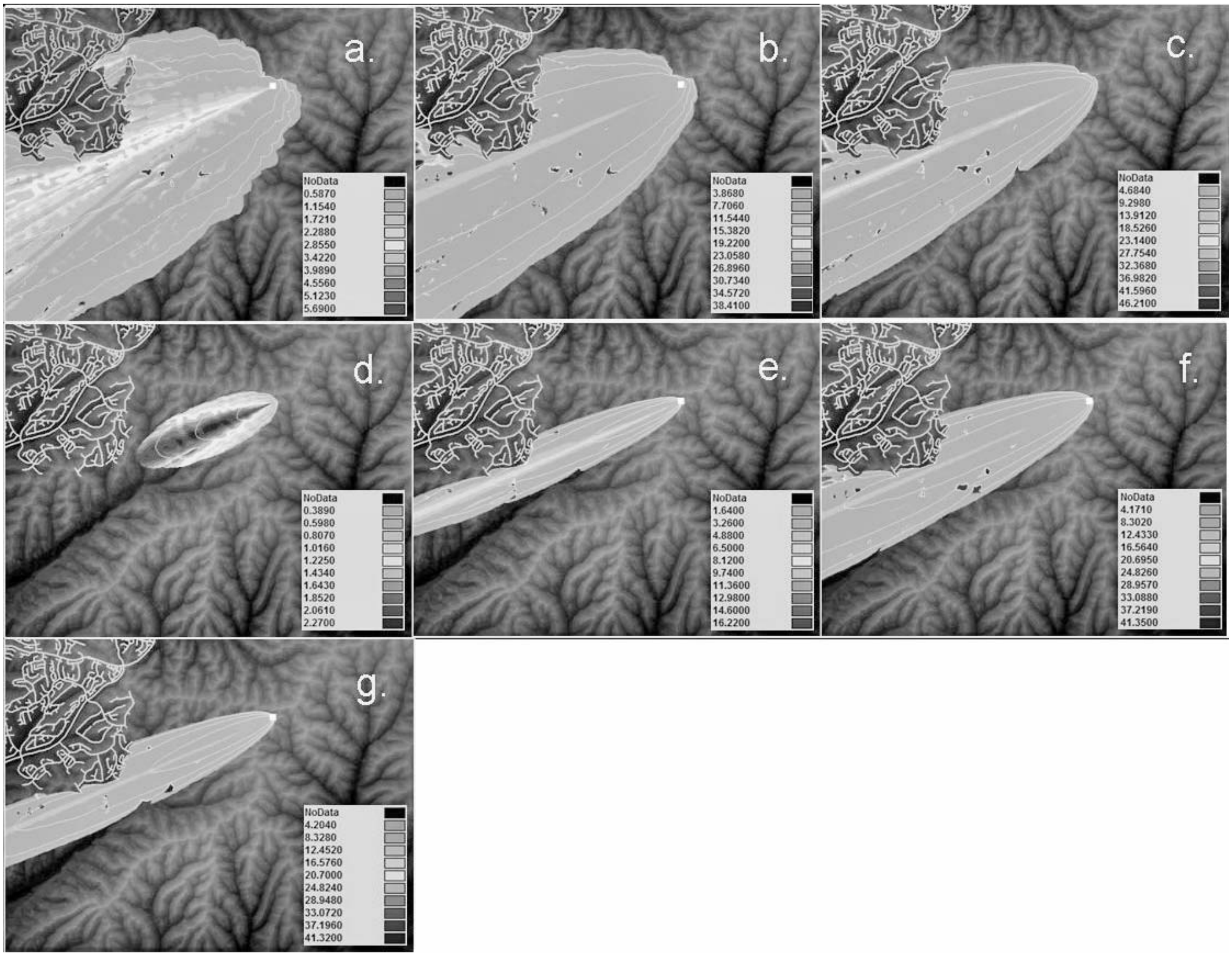

Fig. 3. Simulated fire spread for 3 h under 97th percentile historic weather conditions (September–October) in (a) foothill grasses, (b) nonnative grasses, (c) scrub oak chaparral, (d) coast live oak, (e) chamise chaparral, (f) southern mixed-chaparral, and (g) Diegan coastal sage scrub community types in San Diego County, California.

arral to nonnative grasses (Keeley 2001). Thus, expanding developments in southern California face a self-perpetuating fire and ecological dilemma.

Obviously, one of the more unexpected results of the analysis was the absence of any quantifiable benefits for grassland and shrubland vegetation types. American Forests developed CITYgreen with models based largely on landscapes in the eastern United States and exclusively with trees. For example, calculations of carbon sequestration are based exclusively on tree canopy cover (Nowak and Rowntree 1991, McPherson et al. 1994). And calculations of air pollution removal are based, in part, on pollution data from 10 cities in the United States, the nearest of which to San Diego are Denver, Colorado, and Seattle, Washington. American Forests markets CITYgreen as ‘‘calculating the value of nature’’ and has successfully performed urban ecosystem analyses (UEAs) in eastern cities such as Atlanta, Georgia, Roanoke, Virginia, and Charlotte, North Carolina. In their recent UEA of San Diego (American Forests 2003), they demonstrated not only landscape changes in vegetation cover types, but also monetary savings that tree canopy cover provided and the monetary losses San Diego has experienced due to the loss of tree canopy cover. However, because the dominant cover types in the area are shrublands and grasslands, benefits derived from trees are only a part of the story there. Thus, in areas of the western United States where trees are not historically the major vegetation type, land managers and policymakers must recognize the limitations of CITYgreen and use caution in the interpretation of its results.

Because CITYgreen did not quantify benefits for any of the grassland or shrubland community types, it was impossible to adequately evaluate the different vegetation communities in terms of the best mix of benefits and fire risk. Because coast live oak showed relatively benign fire behavior and demonstrated tangible benefits, it would seem to be the best option in the area. However, the xeric, Mediterranean climate of San Diego constrains coast live oaks largely to canyon bottoms and occasionally to moister north-facing slopes. Even if there was a hypothetical ability to mass-irrigate the landscapes there to facilitate coast live oak, a dilemma in the area is that large trees are commonly cut down by homeowners because they are perceived to degrade residential views.

MANAGEMENT IMPLICATIONS

Even though simulated fire behavior varied considerably by vegetation type in our study, few developments in the wildland–urban interface of southern California should be considered fire ''safe'' during extreme conditions. Vegetation types and structures, construction design, infrastructure, and suppression capabilities all play a role in determining the risk to a given structure. Thus, vegetation management cannot be relied on alone to reduce the risk of wildfire to human developments. Further, fire managers should be aware that although the new 30.48-m (100-ft) clearance regulation is intended to reduce fire intensity, there may be potential for unexpected consequences that could unintentionally increase fire behavior (Dicus and Anderson 2005). For example, thinning some eucalyptus (*Eucalyptus* spp.) stands in San Diego has been shown to increase the amount of nonnative grasses and shrubs in the understory, which created an even more explosive situation than before the thinning occurred (M. Scott, Rancho Santa Fe Fire District, personal communication).

Even though we have reported no benefits, native grasslands and brushlands provide many societal and ecological benefits. Therefore, fire managers must understand the potential benefits of vegetation in an area and recognize that fire risk can be significantly reduced without totally denuding the landscape of vegetation. There is a need in San Diego and throughout southern California for multidisciplinary collaboration to reduce the cycle of repetitive loss from wildfires while simultaneously maximizing other societal values. Laudably, many interface areas in California have initiated local ''FireSafe Councils,'' which target diverse stakeholders such as fire personnel, landscapers, insurance agents, environmentalists, and academics to seek tangible ways to reduce the fire risk locally.

Land managers and policymakers should use caution when utilizing CITYgreen and understand its limitations. Although a UEA readily shows changes in land use and vegetation, its inability to include nontree vegetation in its analyses of societal benefits should cause users a certain degree of skepticism in areas such as San Diego, where trees are not the dominant vegetative cover type.

CONCLUSIONS

Vegetation community types will vary in fire behavior and, although not shown here, provide various levels of benefits based on the species and structure of the vegetation on the landscape. Thus, fire managers in the wildland–urban interface should not utilize a one-size-fits-all, clear-at-all-costs mentality in fuels management. To ensure sustainable developments in the wildland–urban interface, stakeholders from a diversity of disciplines and worldviews must collaborate to determine the best management plan for a given area that simultaneously reduces fire risk and also maximizes the benefits that different vegetation communities provide.

ACKNOWLEDGMENTS

This project was funded by the California Agricultural Research Initiative. We are grateful to Mike Scott, Urban Fire Forester, Rancho Santa Fe Fire District, who provided practical insight into fuel models and fire behavior modeling in the San Diego area. Also, we thank Mike Singleton and Mark Carpenter of KTU+A Landscaping Architecture and Planning in San Diego, who provided data and further insight into community forestry aspects of San Diego.

LITERATURE CITED

American Forests. 2003. Urban ecosystem analysis—San Diego, California: calculating the value of nature. http://www.americanforests.org/downloads/rea/AF_SanDiego.pdf [accessed 1 Oct 2005].

Anderson, H.E. 1982. Aids to determining fuel models for estimating fire behavior. General Technical Report INT-122, U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station, Ogden, UT.

California Department of Forestry & Fire Protection. 2004. California fire siege 2003: the story. http://www.fire.ca.gov/php/downloads/2003FireStoryInternet.pdf [accessed 1 Oct 2005].

Cohen, J.D. 2000. Preventing disaster: home ignitability in the wildland–urban interface. Journal of Forestry 98(3):15–21.

Dicus, C.A., and M.P. Anderson. 2005. Benefits versus fire risk of native and invasive vegetation in the Wildland–Urban Interface. Pages 63–69 *in* C. Pirosko (ed.). Proceedings of the California Invasive Plant Council Symposium 8. 7–9 Oct 2004, Ventura, CA.

Holland, R.F. 1986. Preliminary descriptions of the terrestrial natural communities of California. California Department of Fish and Game, Natural Heritage Division, Sacramento.

Keeley, J.E. 2001. Fire and invasive species in Mediterranean-climate ecosystems of California. Pages 81–94 *in* K.E.M. Galley and T.P. Wilson (eds.). Proceedings of the Invasive Species Workshop: the role of fire in the control and spread of invasive species. Miscellaneous Publication No. 11, Tall Timbers Research Station, Tallahassee, FL.

McPherson, E.G., D.J. Nowak, and R.A. Rowntree (eds.). 1994. Chicago's urban forest ecosystem: results of the Chicago Urban Forest Climate Project. General Technical Report NE-186, U.S. Department of Agriculture, Forest Service, Radnor, PA.

Nowak, D., and R.A. Rowntree. 1991. Quantifying the role of urban forests in removing atmospheric carbon dioxide. Journal of Arboriculture 17(10):269.

Sanders, R.A. 1986. Urban vegetation impacts on the hydrology of Dayton, Ohio. Urban Ecology 9(3/4):361–376.

Taha, H. 1996. Modeling impacts of increased urban vegetation on ozone air quality in the South Coast Air Basin. Atmospheric Environment 30:3423–3430.

Taha, H., S. Douglas, and J. Haney. 1997. Mesoscale meteorological and air quality impacts of increased urban albedo and vegetation. Energy and Buildings 25:169–177.