Testing Patterns of Landowner Propensities to Implement Extensive Forest Fuels Reduction: Agent-based Modeling Experiments in the Willamette Valley, USA

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Abstract

The potential benefits of incentivized, extensive fuels reduction were explored with an agent-based model that simultaneously simulated landowner behaviors, high climate change impacts, vegetation change and wildfire behavior. For a study area including the wildland urban interface around Eugene and Springfield, Oregon, USA, we found that only one or a few landowner types need be included in such a program, and that farmers should not be included, if the public cost-effectiveness of saving homes from wildfire is the goal, rather than saving the maximum number at any cost.

1 Introduction

Wildfires are becoming more frequent, intense and extensive in the western United States, probably as a result of climate change (WESTERLING et al. 2006). Many are burning in mainly privately owned landscapes and often near or into cities in what the U.S. government calls the "Wildland Urban Interface" (WUI) (RADELOFF et al. 2005). So far the main responses in such landscapes have been to combat the fires, attempt to restore ecosystems in some burned areas, and reduce fuel loads nearby homes and other valuable structures to reduce the chance that they will burn. Another approach might be to distribute fuel reduction extensively throughout many private parcels across fire-prone landscapes. This might make these landscapes more resilient to wildfire such that fires should be less intense, spread more slowly and become less extensive. The result might be average wildfire events that pose considerably less threat to homes, and are easier to control without rendering as much long-term ecological damage (HAIGHT et al. 2004).

Fire-dependent oak woodlands and savannas historically dominated the Willamette Valley foothills of western Oregon, USA. 150 years of human settlement and fire suppression are converting these ecosystems into more dense and fire-prone softwood forests near cities and many rural homes. A program of fuels reduction in large patches of forest there might both reduce fire risks to property and forests and also restore scarce habitats. Will landowners comply in sufficient numbers and in an effective landscape pattern (REAMS et

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al. 2005)? How much might financial incentives help among different kinds of landowners (KOONTZ 2001)? If just one kind of landowner were eligible for fuels reduction incentives might that be the most efficient way to reduce overall wildfire risks to properties? We investigated this problem in a study area around Eugene, Oregon by means of an agent based landscape change model driven by landowner behaviors programmed based upon responses from a mail survey (PARKER et al. 2003; AN 2012). This model enables experiments employing different climate change models, different settlement patterns of urban expansion and / or rural residential development, and different types and patterns of forest fuels reduction projects. It is written in Envision modeling software (http://envision.bioe.orst.edu), which is freely available along with the spatial dataset and example code at: http://envision.bioe.orst.edu/StudyAreas/SouthernWillamette. The experiment reported here employed a high climate change model and carbon emissions scenario (Hadley A2) that produces more and larger simulated future wildfires in the study area. The experiment also simulated a pattern of new settlement favoring dispersed rural residents with little expansion of densely settled urban area.

2 Structure of the Model

The model structure is shown in figure 1. Landscape change plays out in a study area map (“1” in figure 1) beginning in 2010, as shown in figure 2. The landowner agents act upon “integrated decision units” (IDU) that are unique polygons (slivers eliminated) determined by overlaying ownership parcels and soils (to capture edaphic differences). IDU were <5HA on <10% slopes and <2HA on >10% slopes. Other GIS data are attributes of each IDU. Figure 3 is a close up view of IDUs. The study area contains more than 81,000 HA, 16,500 tax lots and 86,000 unique IDUs.

The model proceeds over 50 years (in our experiments) whereby every IDU can change year by year (“2” in figure 1) to evolve self-directed landscape patterns. These changes arise via the three submodels affecting the “2” box in figure 1: landowner actions, wildfire, and vegetative succession, and a population growth model not depicted there.

Landowner actions were programmed from a mail survey of a landowner sample in and around the study area (“3” in figure 1). Results identified landowner types according to factor and cluster analyses by their dominant motivations (NIELSEN-PINCUS et al. 2010). Multi-functional small-holder owners typically live in 0.8-8.0 HA parcels, derive income from elsewhere, but also devote part-time to agricultural production (GÓMEZ-LIMÓN et al. 2011). The survey also enabled an efficient probabilistic assignment of agent types to actual parcels (figure 4) based upon where they tend to occupy different kinds of places in the landscape. The annual average probabilistic propensities of each landowner type, with their own forest and land use types, to engage in fuels reduction projects or many other land management actions were also determined from the survey. The influence of financial or property rights incentives, or of other changes in circumstance upon propensities, was ascertained using questions like that in figure 5.

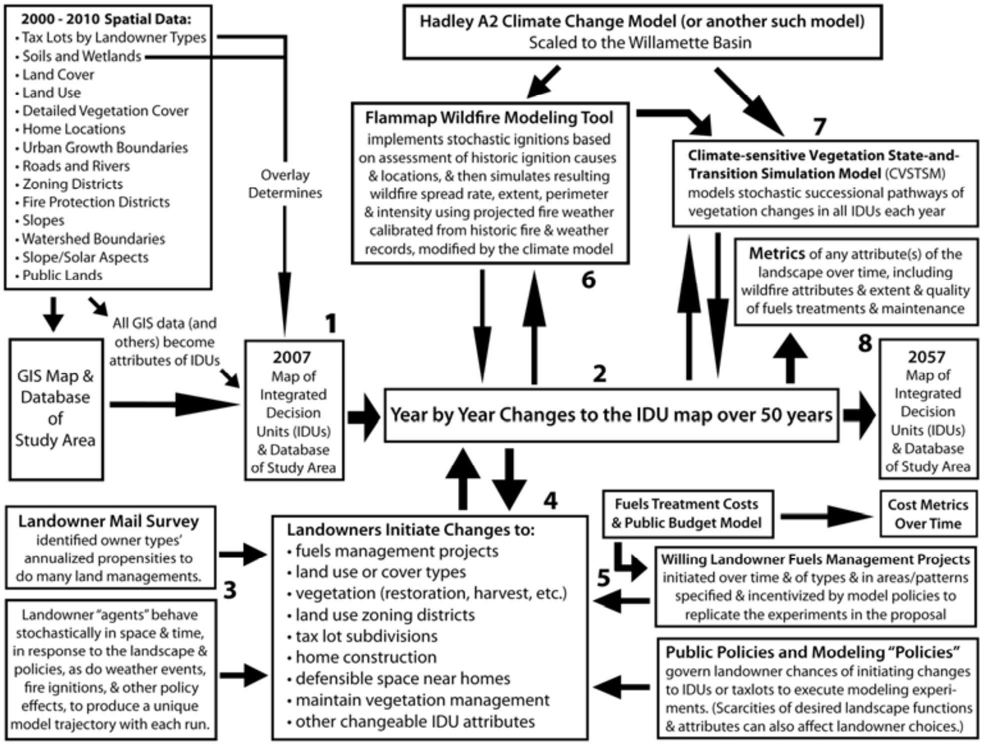

Fig. 1: Agent-based model structure that produces unique, self-directed sequences of landscape changes in the study area over 50 years, as affected by climate change, landowner behaviors, public fuels treatment subsidies, wildfire events and vegetation change. Number labels are referred to in the text.

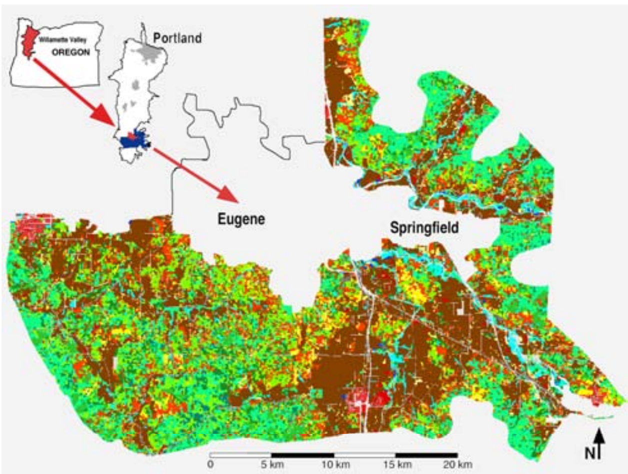

Fig. 2:
The study area in regional context, showing the pattern of 2007 vegetation types at the beginning of experimental runs. Green shades are conifer forests; blues are mesic hardwood forests, browns are agriculture; oranges are oak woodlands, yellows are savannas and prairies, and reds are urban and areas of consolidated small (<0.80 hectare) rural residential parcels.

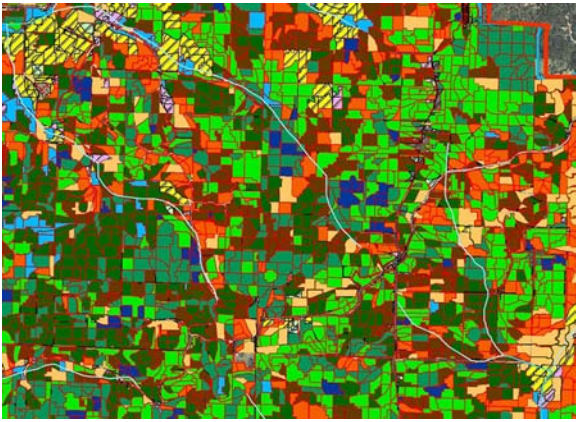

Fig. 3: Close up view of some integrated decision units (IDU) south of Eugene.

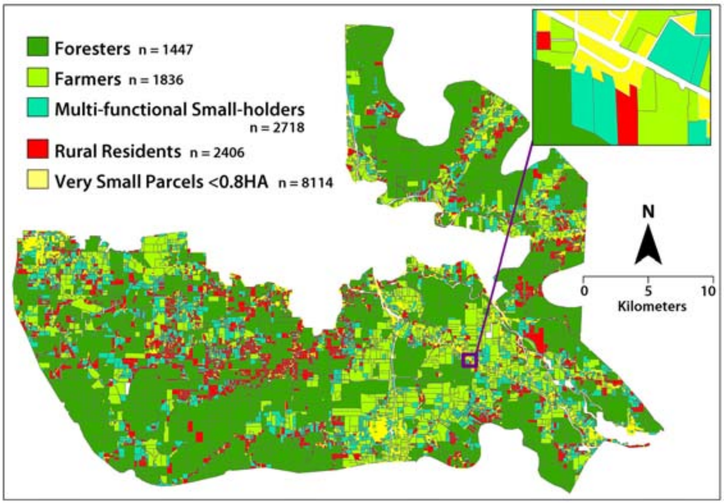

Fig. 4: Initial assignment of landowner types to parcels based upon mail survey responses relating owner types to parcels' sizes, land cover types and improvement values.

These propensities join with other "stimuli" (lower left and right boxes in figure 1) to produce landowner actions upon IDU of the sort listed in box "4" in figure 1. These stimuli may be public policies, fire ignitions, climate / weather changes, relative scarcities of landscape goods, and "policies" that govern the model's execution, such as patterns of zoning changes or urban growth etc. These stimuli may be stochastically generated by a submodel, i.e. climate change, or applied via a fixed set of intentional or random events programmed to occur over time. These stochastic events join with the spatially and temporally unpredictable probabilistic propensities of landowners to adopt changes to their IDU so that earlier landscape changes affect landowners' new actions each year to produce a unique self-directed evolution of the landscape with each model run.

Also affecting the landscape and future landowner actions are the occurrences of wildfires ("6" in figure 1). Our project has taken the established FlamMap wildfire-modeling tool (FINNEY 2006). This program takes an ignition point and weather attributes and forecasts the pattern, intensity and rate of wildfire spread over the landscape, given its topography and pattern of vegetation types. We have adapted it for use in our study area of mixed forest and land cover types (SHEEHAN 2011). This has included calibrating this model to historic wildfire behavior patterns in similar landscapes to the south of our study area, with recent climate regimes like those that are forecast (under the Hadley A2 climate change model employed here) to occur in the Willamette Basin in the future.

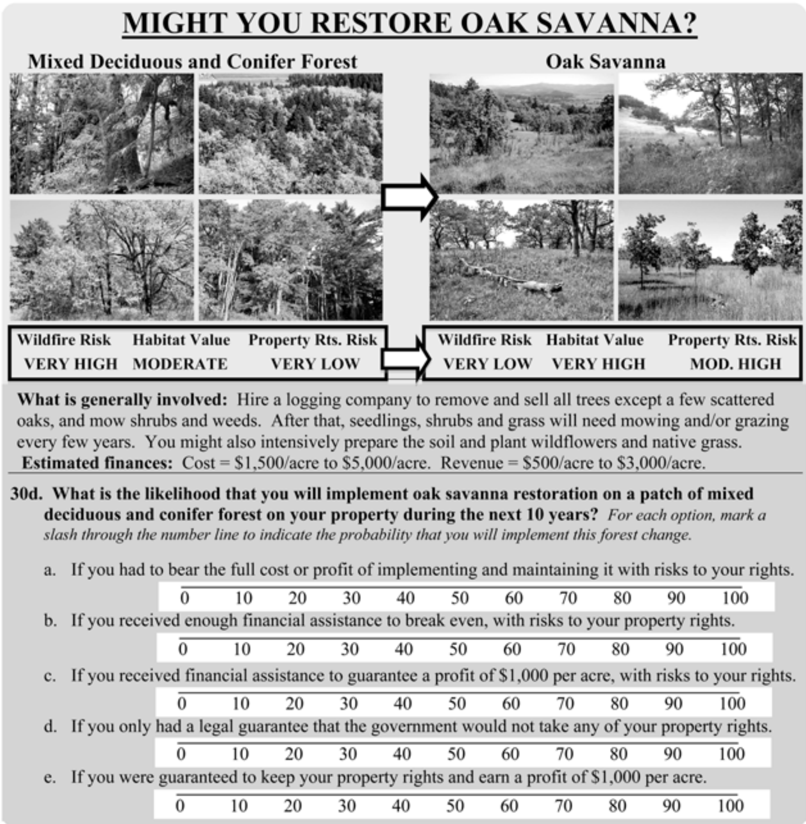

Fig. 5: Example mail survey question querying a landowner's propensities to implement a type of fuels reduction project if offered different kinds of public incentives.

The historic pattern of wildfire ignitions in the foothills of the Willamette Valley (including our study area) over the last 50 years, in relation to population densities, land uses and road locations, was analyzed to produce many well-calibrated stochastic lists of wildfire ignition points across the study area that change over time with the distribution of population, roads and land uses. The regionally scaled and calibrated climate model (top of figure 1) then probabilistically associates a combination of fuel moisture, temperature, humidity and wind speed / direction with each ignition point. FlamMap then uses daily future climate data to generate a spatially simulated wildfire event hour by hour to conclusion, and the vegetation types associated with every affected IDU are changed accordingly at the corresponding year and then forward. The number of homes that encounter the fire and its intensity there are also recorded. A randomly selected example maps of all wildfire footprints over 50 years (under high Hadley A2 climate change) is shown in figure 6.

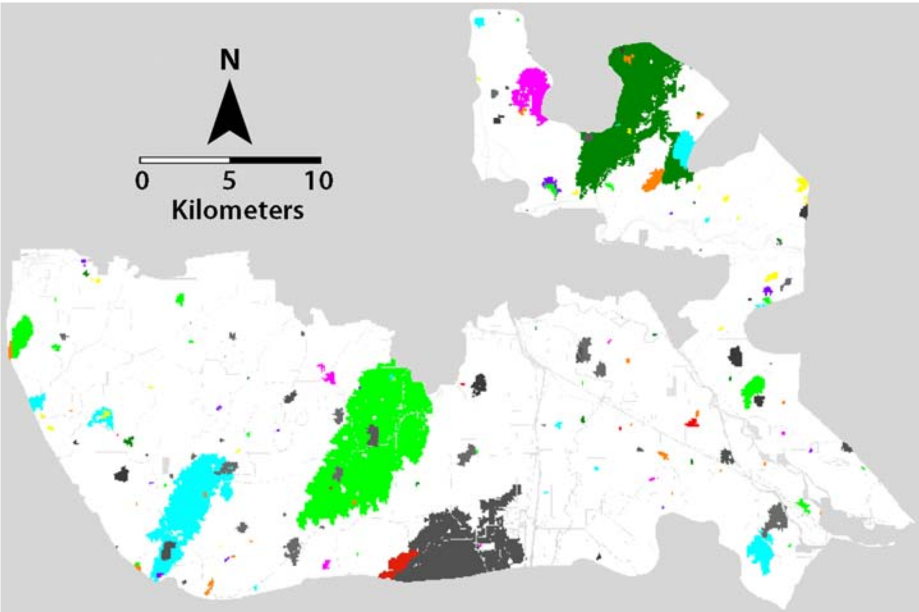

Fig. 6: Wildfire footprints from a random, high climate change, 50-year model run.

Vegetation cover types change over time, due to natural ecological succession and in response to climate change, at the same time that landowners and wildfires are affecting the modeled landscape. The potential pathways by which such vegetation changes can occur due to diverse human, climate-related and other natural disturbances is modeled in our study area (YOSPIN 2012) using a basic state and transition simulation model (STSM) framework derived from the Vegetation Dynamics Development Tool (VDDT) (BEUKEMA et al. 2000) developed at the U.S. Forest Service Olympia Lab of the Pacific Northwest Research Station. It takes the non-agricultural or non-urban vegetation type in any IDU and probabilistically assigns successional changes based on simulations under a wide variety of growth conditions applied to data from 3,000 regional tree plots using the Forest Vegetation Simulator (FVS, CROOKSTON & DIXON 2005). These change into other vegetation types due to the influence of climate change simulated using the dynamic global vegetation model MC1 (LENIHAN et al. 1998). Envision accounts for major disturbances and corresponding vegetation transformations, such as from intense wildfire, or for anthropogenic transformations, such as timber harvests, ecological restorations or abandonment of land management. The successional model also accounts for more subtle land management changes (i.e. removal of livestock, extensive herbicide treatments or forest thinning) in changing the vegetation attributes of IDUs over time. A simplified diagram of our STSM is offered in figure 7.

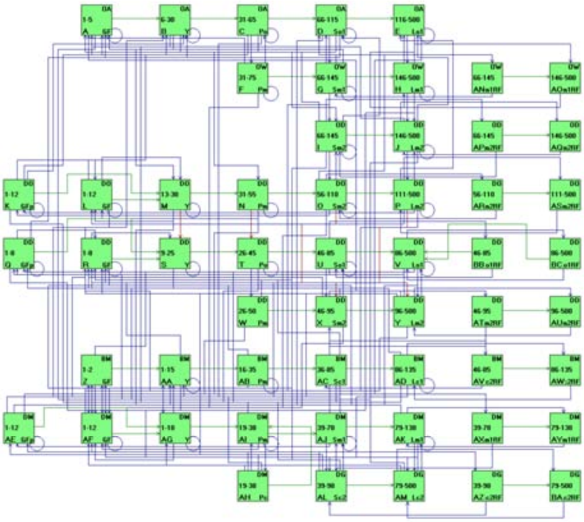

Fig. 7:
Diagram of a portion of the CVSTSM model of potential vegetation types (green boxes) linked by potential pathways of change from year to year (blue lines) due to succession, or human/natural disturbances (Courtesy of Gabriel Yospin).

The product of each model run is a final map of the 2057 landscape with databases of metrics in that year and as they changed year by year over time ("8" in figure 1). Experiments entail 50 runs of the same scenario, with the same initial landscape and modeling code, and by averaging metrics in year 2057 and over the 50 years to get there.

3 Targeting Fuels Reduction Incentives to Different Landowner Types

A good use of this agent-based model is to pose complex questions that it can best answer: If many landowners were to conduct spatially extensive fuels reduction projects (instead of just near homes) might this reduce the spatial extent and severity of wildfires or the number of homes they threaten over time? If these projects were subsidized by public funds and political or budget constraints required that incentives be targeted at only one landowner type, how well might such a policy achieve these goals? This question is confounded by different tendencies across owner types: (1) the kinds of places they occupy, (2) forests types owned, (3) parcel sizes, (4) propensity to perform fuels reduction by thinning forests (with and without incentives), (5) propensity to perform fuels reduction by restoring habitats (with and without incentives), (6) cost of projects preferred, (7) location of such projects in relation to concentrations of homes, and (8) topographic location of such projects in relation to ignition sources, topography and winds affecting fire behavior.

We projected landscape futures to investigate this question (like Yin 2010) by use of the submodel labelled "5" in Figure 1. Local professionals who implement fuels reduction projects identified best methods for different projects (ULRICH 2010) and their average costs (table 1) and revenues (table 2). We set an annual budget limit of $750,000 to fund only cost-reimbursement incentives for forest thinning or ecological restoration, depending on landowners' forest types and project selection propensities. Projects were funded to willing volunteers each year, except in rare years when insufficient funds were available – when project funding favoured locations within the WUI. We modeled projects to fill the full extent of eligible forest types within each parcel. The full model ran year-by-year as these projects were implemented in an un-designed, self-directed pattern of locations, concurrent with wildfires, new home construction and vegetation change. Experiments targeting different landowner types were conducted, each with its own expenditures of public funds (table 3). We also ran two more experiments as comparative references: (1) no financially incentivized fuels reduction projects; and (2) offering incentives to all landowner types, not just one, with a larger budget that averaged $420,000/year.

4 Results

Figure 8 shows the average cumulative implementation of incentivized fuels treatment projects across all runs within each of the experiments that targeted a different landowner type. Data are reported in two time points because the first 25 years tends to be a ramp-up period before enough projects have occurred to begin to appreciably affect wildfire behavior. Implementation and maintenance of fuels treatments over years 26-50 tends to grow in impacts upon wildfire behavior. If any one landowner type is provided with incentives, they tend to produce 1/3 to 1/2 as many HA of treatments as when all landowner types are offered the same. Foresters and rural residents tend to perform about 50,000 more HA of thinning than farmers and multi-functional smallholders (figure 8A). Only rural residents are less productive of projects aimed at habitat restoration (oak woodland, oak savanna, or prairies) than three other landowner types (figure 8B). This pattern of differences persists when accounting for all fuels treatment types together (figure 8C) where the three other landowner types by themselves tend to implement projects in half as much area as when all types are offered incentives.

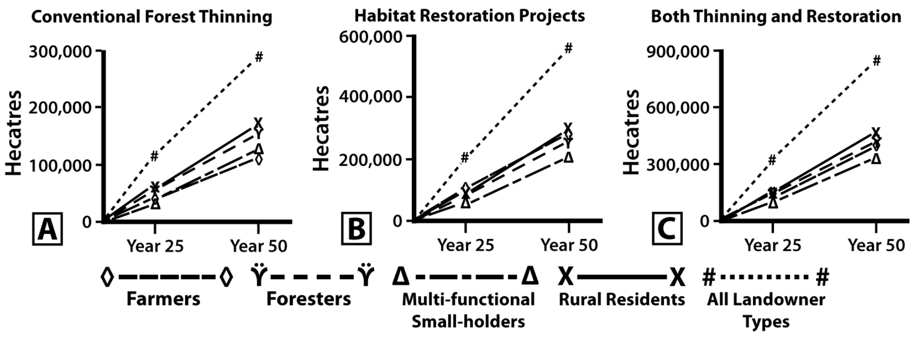

Fig. 8: Average cumulative area of extensive fuels reduction project types across 50 model runs within five separate experiments targeting incentives to different landowner types (Voluntary, un-incentivized projects are not included).

Table 1: Average estimated costs of general fuels treatment project categories across 130 initial detailed vegetation community types.

Existing Gen. Veg. Type	Desired Future Gen. Veg. Type	1st Best Man. Prac.	2nd Best Man. Prac.	3rd Best Man. Prac.	4th & 5th Best Man. Prac.	Cost/HA
Oak Savanna	Full Oak Savanna	skid-steer shear/mow	brdcst herbicide	burn	drill seed	$1,600.00
	Oak Savanna Struc.	skid-steer shear/mow	spot herbicide			$870.00
	Full Oak Wdlnd	skid-steer shear/mow	brdcst herbicide	drill seed		$1,250.00
	Oak Wdlnd Struc.	skid-steer shear/mow	spot herbicide			$870.00
	Fuels Red. Thin.	N/A	N/A	N/A	N/A	N/A
Oak Woodland	Full Oak Savanna	harvester/forwarder	cut stumps	brdcst herbicide	burn, drill seed	$2,280.00
	Oak Savanna Struc.	harvester/forwarder	cut stumps	spot herbicide	broadcast grass	$1,680.00
	Full Oak Wdlnd	harvester/forwarder	cut stumps	brdcst herbicide	drill seed	$1,930.00
	Oak Wdlnd Struc.	harvester/forwarder	cut stumps	spot herbicide	broadcast grass	$1,680.00
	Fuels Red. Thin.	harvester/forwarder				$1,000.00
Broadleaf Forest	Full Oak Savanna	harvester/forwarder	cut stumps	spot herbicide	burn, sew seed	$2,755.00
	Oak Savanna Struc.	harvester/forwarder	cut stumps	spot herbicide	broadcast grass	$1,880.00
	Full Oak Wdlnd	harvester/forwarder	cut stumps	spot herbicide	broadcast seed	$2,405.00
	Oak Wdlnd Struc.	harvester/forwarder	cut stumps	spot herbicide	broadcast grass	$1,880.00
	Fuels Red. Thin.	harvester/forwarder				$1,000.00
Mixed Forest	Full Oak Savanna	harvester/forwarder	cut stumps	spot herbicide	burn, sew seed	$2,555.00
	Oak Savanna Struc.	harvester/forwarder	cut stumps	spot herbicide	broadcast grass	$1,680.00
	Full Oak Wdlnd	harvester/forwarder	cut stumps	spot herbicide	broadcast seed	$2,205.00
	Oak Wdlnd Struc.	harvester/forwarder	cut stumps	spot herbicide	broadcast grass	$1,680.00
	Fuels Red. Thin.	harvester/forwarder				$1,000.00
Conifer Forest	Full Oak Savanna	harvester/forwarder	cut stumps	spot herbicide	burn, sew seed	$2,355.00
	Oak Savanna Struc.	harvester/forwarder	cut stumps	spot herbicide	broadcast grass	$1,480.00
	Full Oak Wdlnd	harvester/forwarder	cut stumps	spot herbicide	broadcast seed	$2,005.00
	Oak Wdlnd Struc.	harvester/forwarder	cut stumps	spot herbicide	broadcast grass	$1,330.00
	Fuels Red. Thin.	harvester/forwarder				$800.00

Table 2: Average estimated revenues of general fuels treatment project categories across 130 initial vegetation community types.

Existing General Vegetation Type	Desired Future General Vegetation Type	Average Income Potential Estimate From Logs: 2010	Av. Inc. Pot. Est. Chips: 2005 & 2010	Total Income Potential Estimate: 2010	Av. Inc. Potential Estimate From Logs: 2005	Total Income Potential Estimate: 2005-2010
Oak Savanna	Full Oak Savanna	$0	$0	$0	$50	$50
	Full Oak Woodland	$0	$0	$0	$0	$0
	Fuels Red. Thinning	$0	$0	$0	$0	$0
Oak Woodland	Full Oak Savanna	$100	$400	$500	$550	$950
	Full Oak Woodland	$100	$250	$350	$450	$700
	Fuels Red. Thinning	$50	$250	$300	$200	$450
Broadleaf Forest	Full Oak Savanna	$50	$900	$950	$250	$1,150
	Full Oak Woodland	$50	$750	$800	$150	$900
	Fuels Red. Thinning	$50	$650	$700	$250	$900
Mixed Forest	Full Oak Savanna	$600	$700	$1,300	$3,000	$3,700
	Full Oak Woodland	$500	$600	$1,000	$2,400	$3,000
	Fuels Red. Thinning	$250	$450	$700	$1,350	$1,800
Conifer Forest	Full Oak Savanna	$1,500	$300	$1,850	$7,600	$7,900
	Full Oak Woodland	$1,400	$250	$1,700	$7,100	$7,350
	Fuels Red. Thinning	$600	$250	$850	$3,000	$3,250

Table 3: Fuels reduction subsidies paid to owner types in separate experiments.

Landowner Type	Years 1 – 25	Years 1 – 50
Farmers	$9,873,925	$17,002,788
Foresters	$8,324,334	$15,492,054
Multi-functional Small-holders	$5.612,604	$13,437,946
Rural Residents	$9,843,342	$23,360,527
All Owners	$20,141,598	$40,884,639

Figure 9 shows the experiments' impact on key metrics of wildfire hazard compared to the no incentivized fuel management reference. The extent of the study area that experienced any form of wildfire up to year 25 is reduced when all but the farmers gets exclusive claim on incentives (figure 9A). This occurs despite increasing numbers of ignitions due to population growth and increasing frequency of fire promoting weather. After that, targeting incentives to either farmers or multifunctional small-holders exhibited an increase in the extent of wildfires compared to the no incentives reference (figure 9A). This is because wildfires that encounter areas that have experienced ecological restoration tend to burn mostly along the ground, but spread further and faster. Only the reference experiment incentivizing all landowners together substantially reduced fires' overall extent. Figure 9B shows that all experiments reduced the extent of more severe, stand replacing wildfires that burn through the canopy of forests, although the farmers or multi-functional small-holders did so very little.

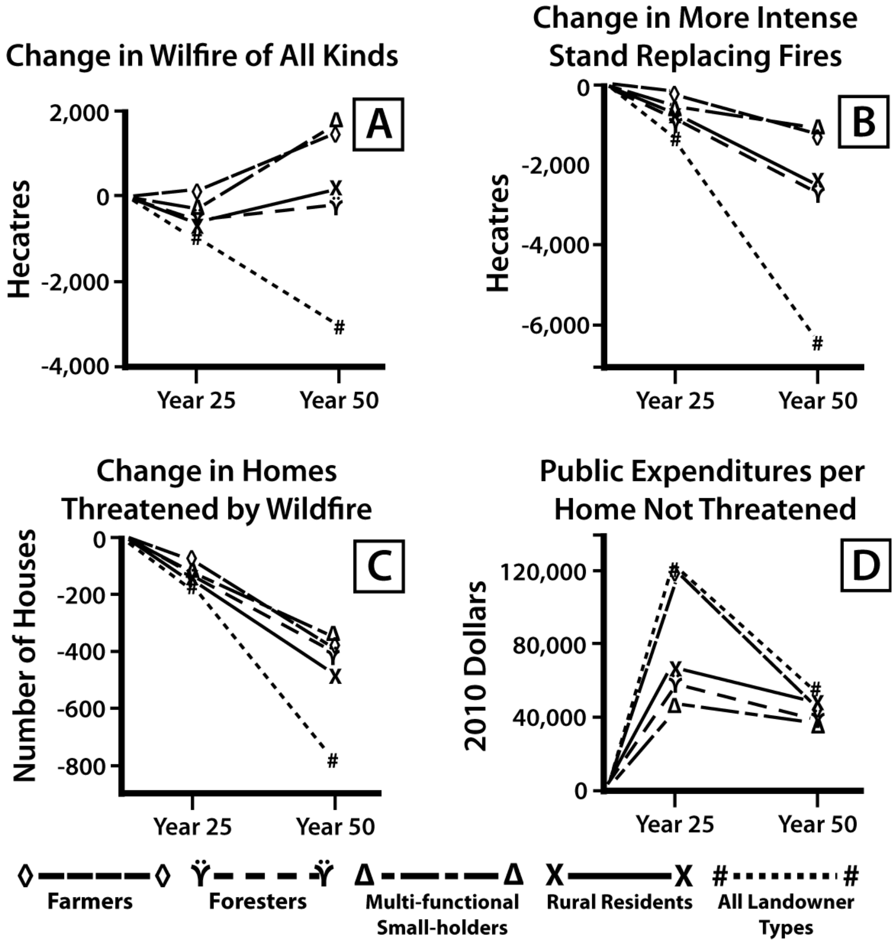

Fig. 9: The effect of financial incentives for extensive fuel reduction projects targeted separately at different land owner types compared to the average model run without any such incentives.

We defined wildfire threatened homes as all that encounter a stand replacing fire, or a less intense fire and without fire-defensible space around the structure – a propensity modelled from the mail survey. All the experiments showed substantial reduction in threatened homes compared to the no incentives reference (figure 10C). Targeting any one landowner type with fuels reduction incentives tends to produce half as much reduction in threatened homes as targeting all landowners. Rural residential owner incentives perform the best, perhaps because such projects tend to reduce wildfire intensity most often near homes.

The findings in figure 9 and figure 10A-C combine with the expenditures in table 1 (figure 10D) to suggest a policy implication. If budget constraints demand a cost-effective program of extensive fuel reduction, then it is best not to include all owner types nor farmers. This may be because farmers are disposed to over-participate in the program (suggested by our mail survey) to reduce fuels in small forest patches often among croplands. These may often be isolated from larger forested areas that transmit wildfire, or tend to own lands with more oak vegetation types than foresters. The most cost effective way to reduce the loss of homes to wildfire is to target incentives only to rural residents or foresters or multi-functional owners, or a spatially intelligent combination of these.

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