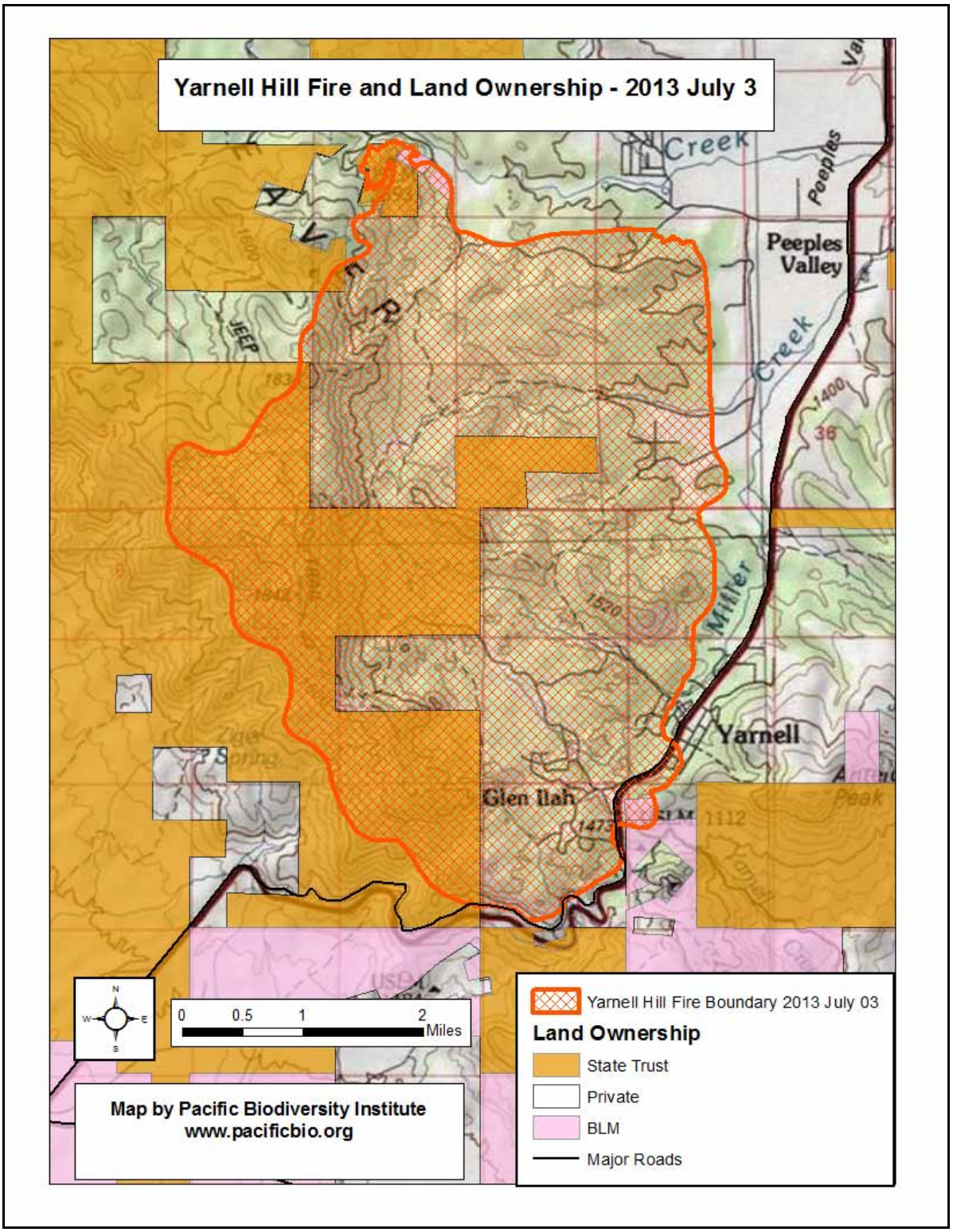
ANALYSIS AND COMMENTS ON THE YARNELL HILL FIRE IN ARIZONA AND THE CURRENT FIRE SITUATION IN THE UNITED STATES



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Analysis and Comments on the Yarnell Hill Fire in Arizona and the Current Fire Situation in the United States

July 2013

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Executive Summary and Key Findings and Recommendations

Pacific Biodiversity Institute undertook a rapid analysis of the 2013 Yarnell Hill Fire and the national wildfire situation to help clear up some questions and misinformation that have spread about this fire and about wildfires in general in the United States.

The Yarnell Hill Fire burned in private lands and lands managed by the State of Arizona. Over 68% of the burned area was on private land. About 31% was on State land and less than 1% was on federal BLM land. The land ownership of wildfires occurrences at a national level is similar to that of the Yarnell Hill Fire. The relationship between fire occurrences and land ownership falls into a consistent pattern year after year. We analyzed the National Fire Information Center's (NFIC) historical fire data for the last 20 years (1993 to 2012) and found that on average, 78 percent of wildfire occurrences are on state and private lands compared to 12 percent of National Forest land (U.S. Forest Service). The remaining 10% occur on other federal ownerships and tribal land (BIA). This information is highly relevant to the development of national wildfire policies. From a national wildfire perspective, wildfires on national forest land are much less significant than wildfires on state and private lands. Note: NFIC is a part of the National Interagency Fire Center (NIFC).

The Yarnell Hill Fire burned through chaparral shrublands. It was not a forest fire. There is a common misperception that wildfires are forest fires. This is typical of the national situation, where many wildfires burn through shrublands and grasslands, not forests. An analysis of the national wildfire situation reveals that most wildfires burn non-forested vegetation, on non-federal land - not forests in the federal domain. These basic facts are often ignored by the media and by politicians when national wildfire policies are debated.

The fact that the Yarnell Hill Fire grew out of control was predictable. The interior chaparral shrublands that it burned through are notorious for high intensity wildfire. There was extreme fire weather during the fire coupled with very dry vegetation as a result of long-term drought, high temperatures, intense sunshine and persistent winds. Unfortunately, it appears that insufficient attention was placed on the critical warning signals of extreme fire weather and fuel conditions, leading to an unfortunate loss of lives.

We have found no evidence that environmentalists discouraged any government agency from thinning and clearing the brush in this area. In fact, no mechanisms exist for environmental groups to comment or interfere with fuel management activities on the private and state land in Arizona.

PBI conducted a rapid assessment of homes and other structures inside the southeast perimeter of the Yarnell Hill Fire to determine how many had tree and shrub canopies touching them or overlapping their roofs. We used Google Earth to do that assessment. This analysis gave us a preliminary estimate of the number of potentially fire-safe homes and other major structures. We found that 89% of the homes and other structures appeared to be in direct contact with trees or shrubs.

After we conducted the assessment describe above, we obtained preliminary data on the houses that actually burned in the fire. This data was developed by Yavapai County from assessor records and maps. We were able to do a quick comparison of the structures we had marked as potentially fire-safe with the structures that actually burned. We found that 95% of the structures we had marked as potentially fire-safe survived and, at most, 5% burned. This compares very favorably to the 30% of the structures that we had identified as not fire-safe

that burned in the fire. The contrast between these two structure survival rates is substantial and illustrates that simple and inexpensive measures, like keeping flammable vegetation away from homes, can have a real impact on the ability of a home to survive a wildfire. We concluded that the residential communities of Glen Ilah and Yarnell were not well prepared for wildfire. It is no surprise that over 100 homes burned.

Preventing fire tragedies in the future demands fire-adapted communities. Tragedies like the Yarnell Hill Fire are preventable. There are simple things homeowners can do to avoid having fires burn into our communities and homes and to prevent firefighter deaths. The focus of national wildfire policy should shift from fire suppression to fire adaptation, rather than spending billions of dollars every year trying to fight wildfires - often with little success. There should be more effort put into initial attack (when firefighters can be most effective) and firefighters need to stand down once the wildfires get to be very hard to control. A much wiser use of our tax dollars would be to use this money to help homeowners and communities create fire-adapted homes and defensible spaces.

Most importantly, to prevent a tragedy like the 19 deaths that occurred on the Yarnell Hill Fire, citizens and elected officials need to be much more careful about deploying firefighters in extremely hazardous situations where they are risking their lives to protect property. The extreme natural forces involved with many wildfires are often much stronger than anything we have to fight them with. We need to learn not to put young men and women in situations where they have little hope of survival.

Introduction

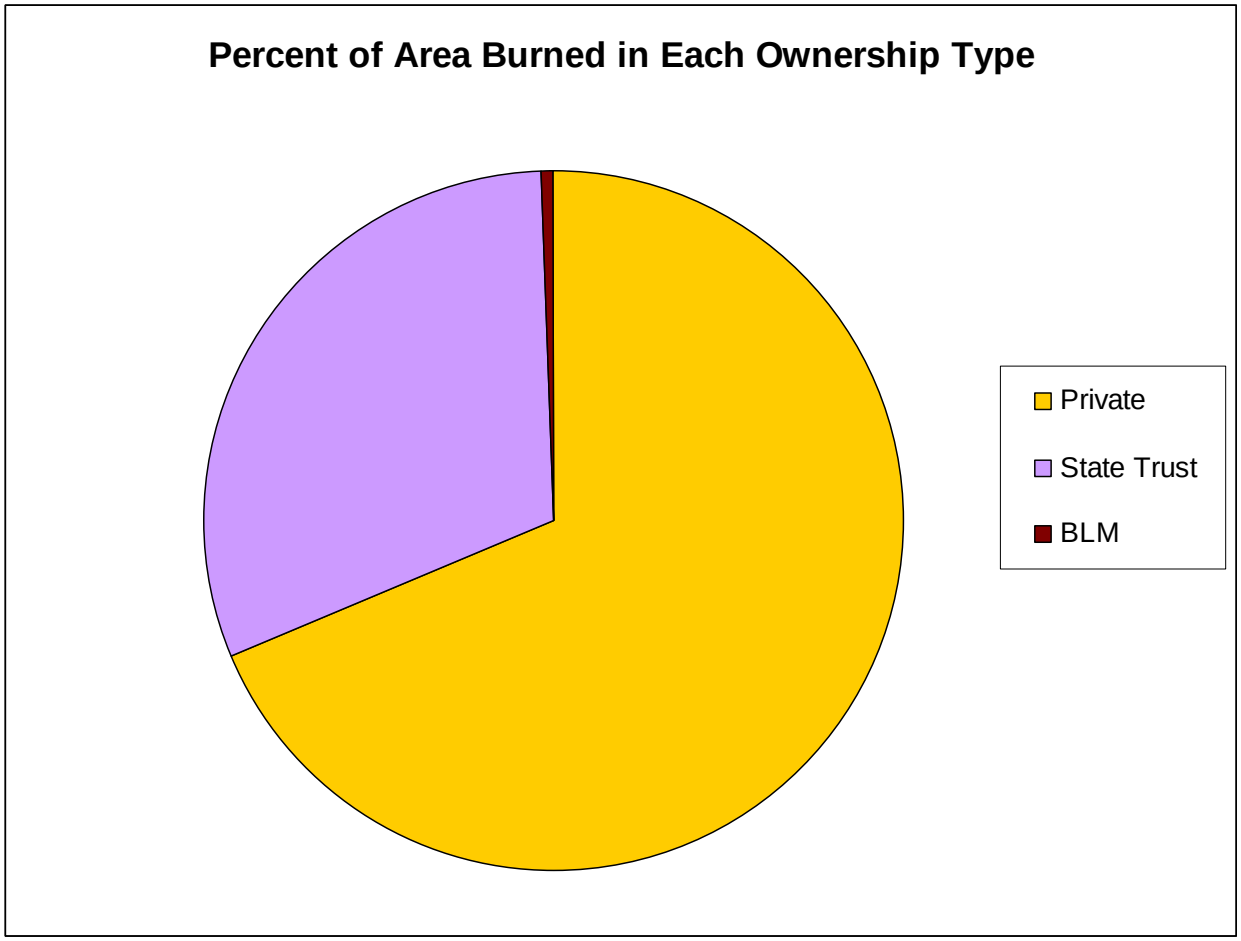
On Friday, June 28, 2013, lightning ignited a fire on Yarnell Hill, near the town of Yarnell, Arizona, about 80 miles northwest of Phoenix. On Sunday, June 30, nineteen firefighters from the Prescott Fire Department's interagency Granite Mountain Hotshots died while trying to fight the fire. By the Fourth of July, the Yarnell Hill Fire had burned over 8,300 acres of tinder-dry chaparral, grasslands and residential neighborhoods.

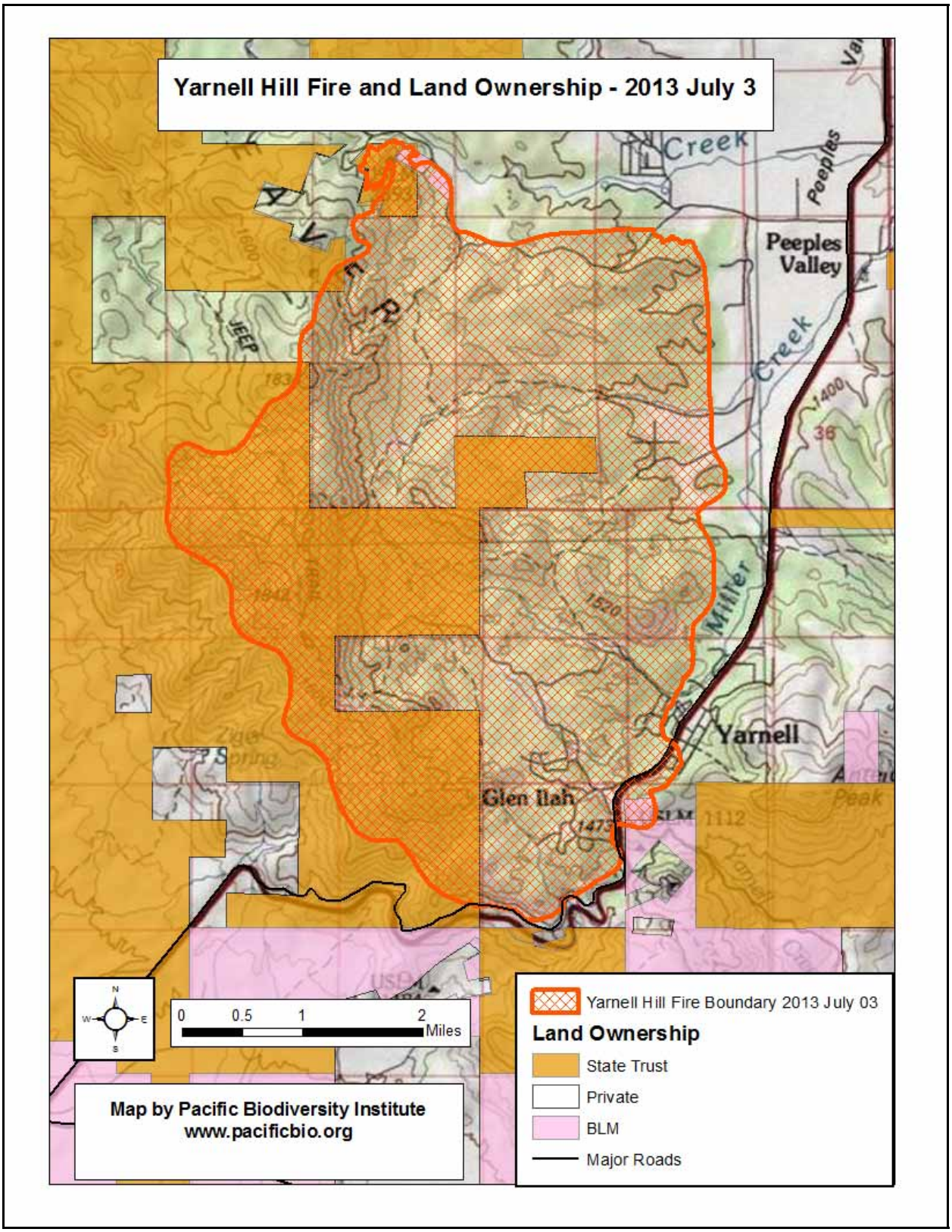
Pacific Biodiversity Institute undertook a rapid analysis of this fire in response to information requests and interest from the news media and widespread national news coverage. Our quick study clears up some questions and misinformation that have spread about this fire and about wildfires in general in the United States.

The Yarnell Hill Fire burned on state and private land

The fire burned in private lands and lands managed by the State of Arizona. The table, chart and map below illustrate the ownership of the area burned. Over two-thirds of the burn area has been on private land. No National Forest land is involved. The nearest National Forest land is on the Prescott National Forest over 10 miles away. Less than 1% of the fire area involves federal BLM lands.

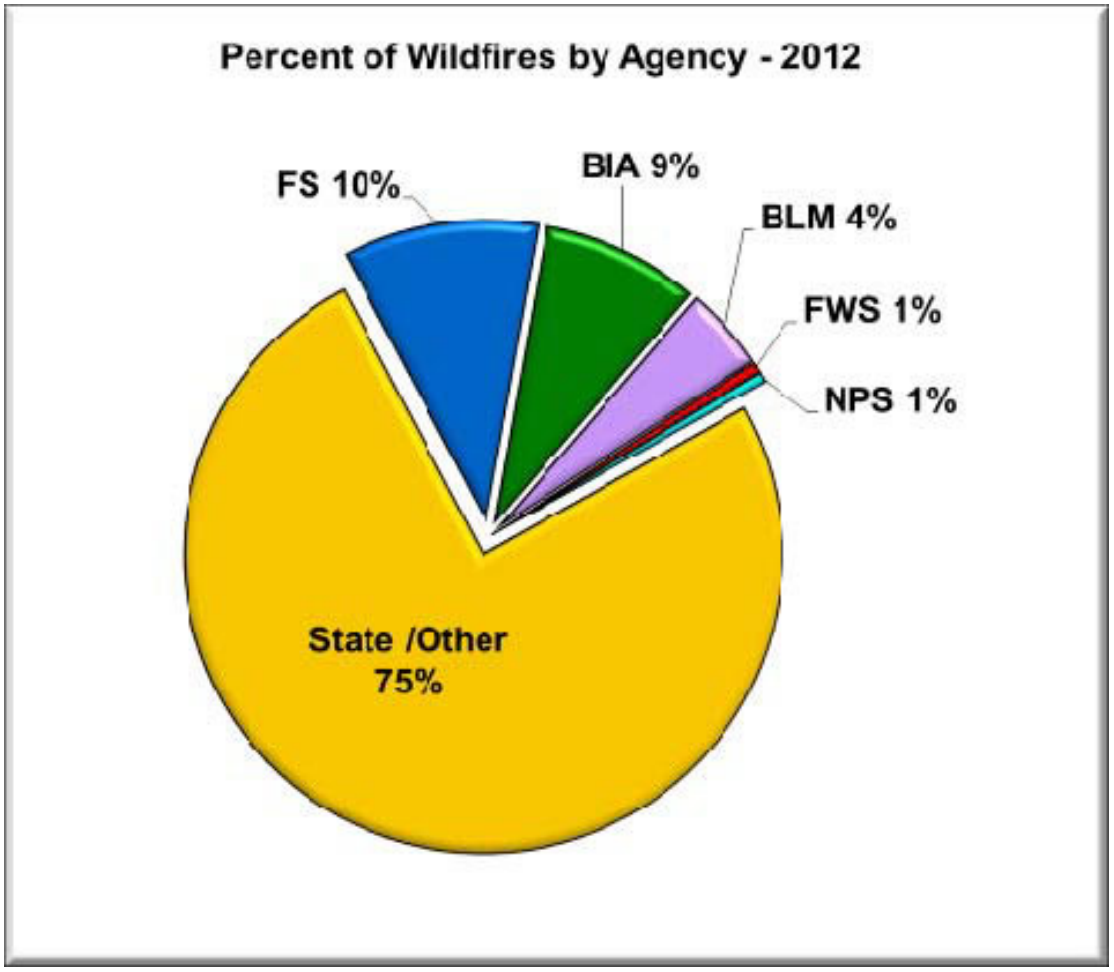
Ownership	Percent of area burned	Acres burned in each ownership
Private	68.5 %	5694.0
State Trust	30.9 %	2564.5
BLM	0.6 %	48.3


Percent of Area Burned in Each Ownership Type
Private
State Trust
BLM

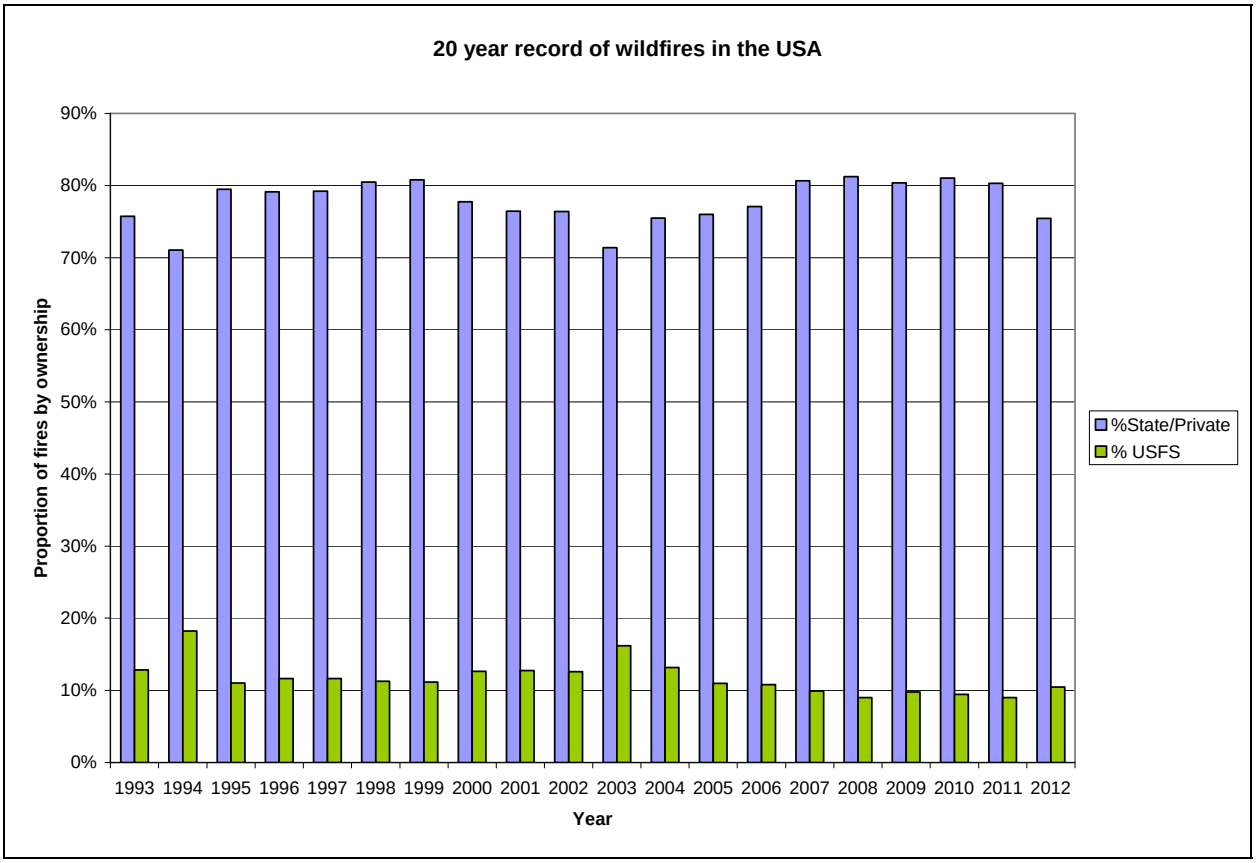

Yarnell Hill Fire and Land Ownership - 2013 July 3
Peeples Valley
Yarnell
Glen Ilah
Miller Creek
Peeples Creek
JEEP TR
0 0.5 1 2 Miles
N
W
E
S
Map by Pacific Biodiversity Institute
www.pacificbio.org
Yarnell Hill Fire Boundary 2013 July 03
Land Ownership
State Trust
Private
BLM
Major Roads

The land ownership pattern in the Yarnell Hill Fire is typical of the national wildfire situation

The land ownership of wildfires occurrences at a national level is currently quite similar to that of the Yarnell Hill Fire. According to the National Fire Information Center's (NFIC) current situation report (2013 July 5), only 9 percent of the wildfire occurrences this year have been on National Forest land compared to 79 percent on state and private land. This is consistent with the entire last year (2012) when 75 percent of the wildfires occurred on state and private land, while only 10 percent occurred on National Forest land (U.S. Forest Service). The pie chart below is from NFIC.



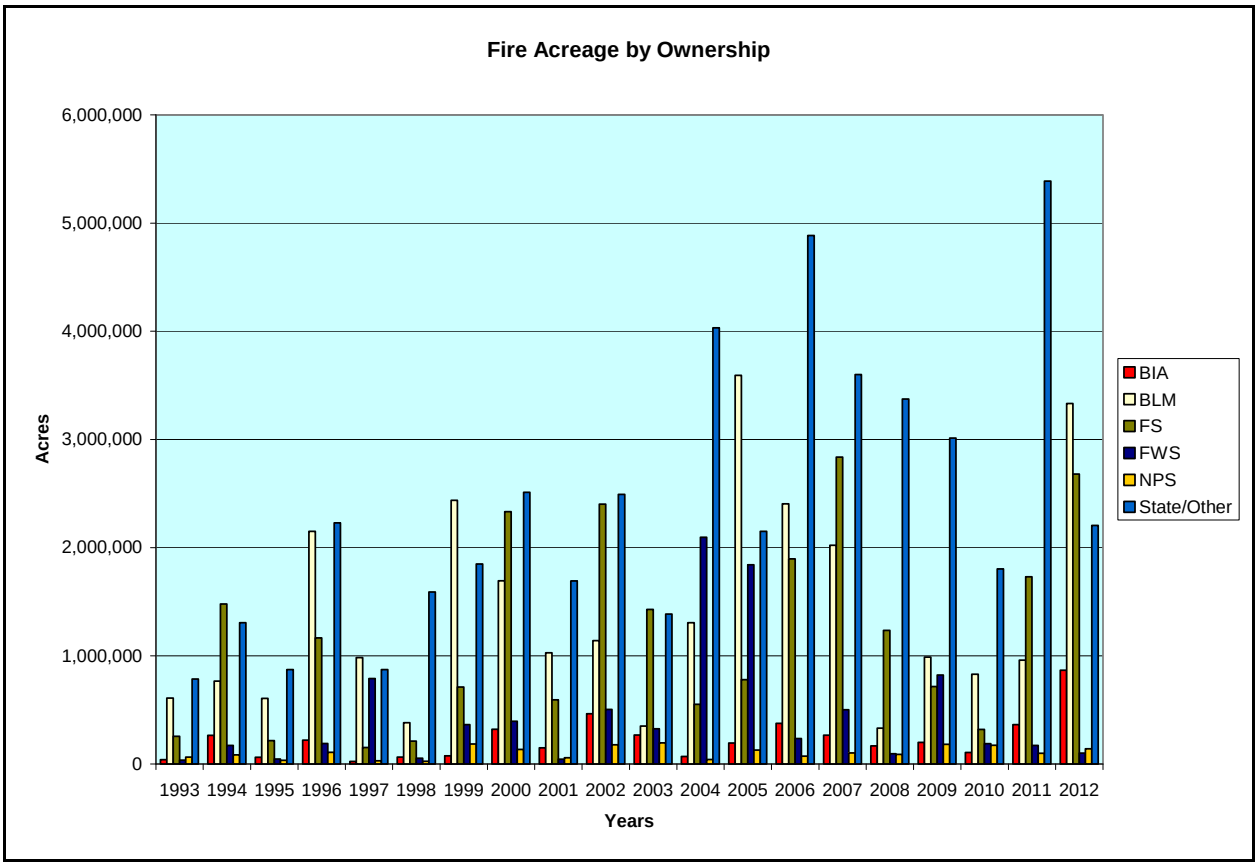
The relationship between fire occurrences and land ownership falls into a consistent pattern year after year. In fact, our analysis of the National Fire Information Center's (NFIC) historical fire data reveals that over the last 20 years (1993 to 2012), on average, 78 percent of wildfire occurrences are on state and private lands compared to 12 percent of National Forest land (U.S. Forest Service). The remaining 10% occur on other federal ownerships and tribal land (BIA). See chart below.

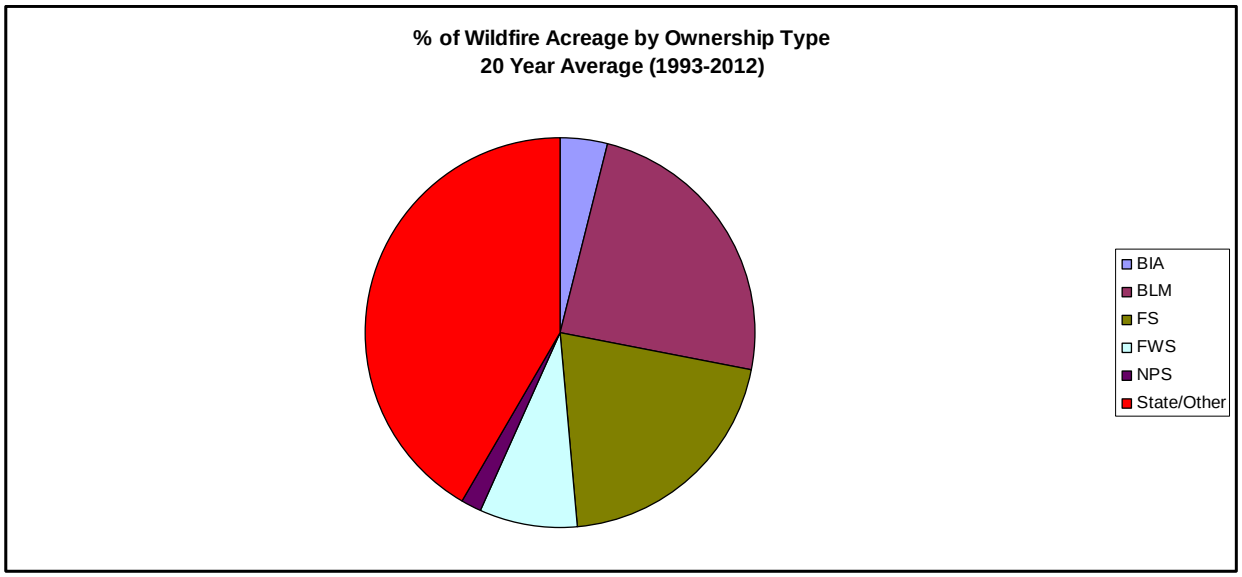


20-year record of wildfire occurrences from the annual historical summary data provided by NFIC

The amount of acreage burned by wildfires in each ownership type every year on a national basis is a more complex picture than the number of fires that originate in each ownership type. The two charts below illustrate the 20-year record of the acreage burned in each ownership type. In 14 of the last 20 years, more area burned in the state and private land category than in any other ownership class. In 4 of the last 20 years more area burned on BLM lands (mostly shrublands, desert and grasslands) than any other ownership class. Only in 2 of the last 20 years (1994 and 2003) did the more land burn in Forest Service land than any other ownership class.

The above information is highly relevant to the development of national wildfire policies. Wildfires on National Forest land account for only 12% of the fire occurrences and 21% of the acres burned across the USA over the last 20 years. This compares to the more significant issue of wildfires on state and private lands which comprise 78% of the fires and 42% of the acres burned during the same time interval. Most wildfires burn non-forested vegetation, on non-federal land - not forests in the federal domain. These basic facts are often ignored by the media and by politicians when national wildfire policies are debated.


Fire Acreage by Ownership
6,000,000
5,000,000
4,000,000
3,000,000
2,000,000
1,000,000
0
Acres
1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012
Years
BIA
BLM
FS
FWS
NPS
State/Other


% of Wildfire Acreage by Ownership Type
20 Year Average (1993-2012)
BIA
BLM
FS
FWS
NPS
State/Other

The Yarnell Hill Fire was a chaparral fire, not a forest fire

According to the Native Vegetation Map provided by the Arizona State Land Department the area that burned was interior chaparral shrublands and semi-desert grasslands. News reports describe the fire burning tinder-dry chaparral and grasslands. Interior chaparral is usually dominated by shrub live oak (*Quercus turbinella*), manzanita species (*Arctostaphylos* spp.), desert ceanothus (*Ceanothus greggi*) and mountain mahogany (*Cercoparpus* spp.). Some juniper (*Juniperus* spp.) may also be present at the upper elevation ecotone.

The natural fire regime for interior chaparral is dominated by high severity wildfires every 50 to 100 years. However, the fire return interval appears to be highly variable between sites. One pilot study conducted in the Prescott National Forest northeast of the Yarnell Hill Fire determined a fire return interval of 30-39 years. (Brooks et al 2007 and Molly E. Hunter (NAU professor) undated presentation).

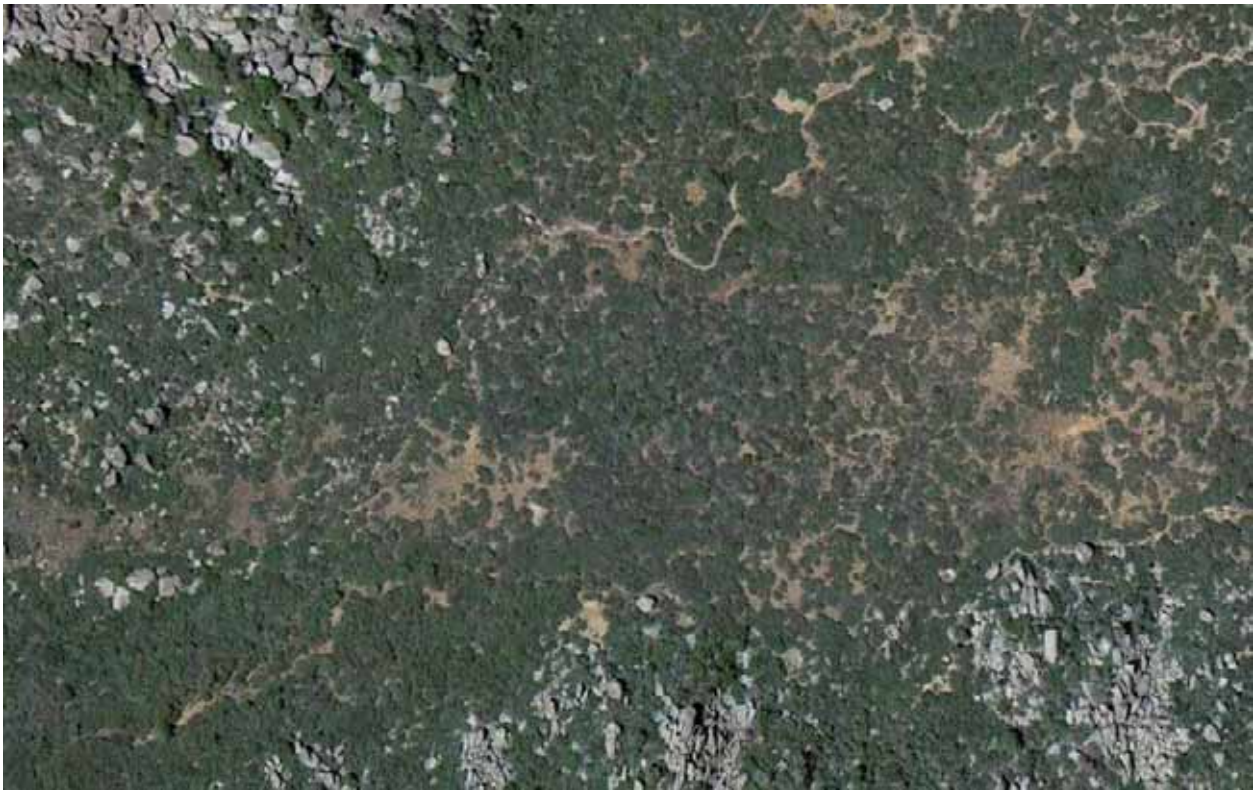
PBI's analysis of Google Earth's high-resolution aerial photography of the area indicates that the fire burned mostly through dense chaparral, with some scattered juniper and oak, large patches of exposed rock, residential neighborhoods and some grasslands.

Below are some examples of pre-fire aerial images of the vegetation and land use pattern of the area burned by the Yarnell Hill Fire.

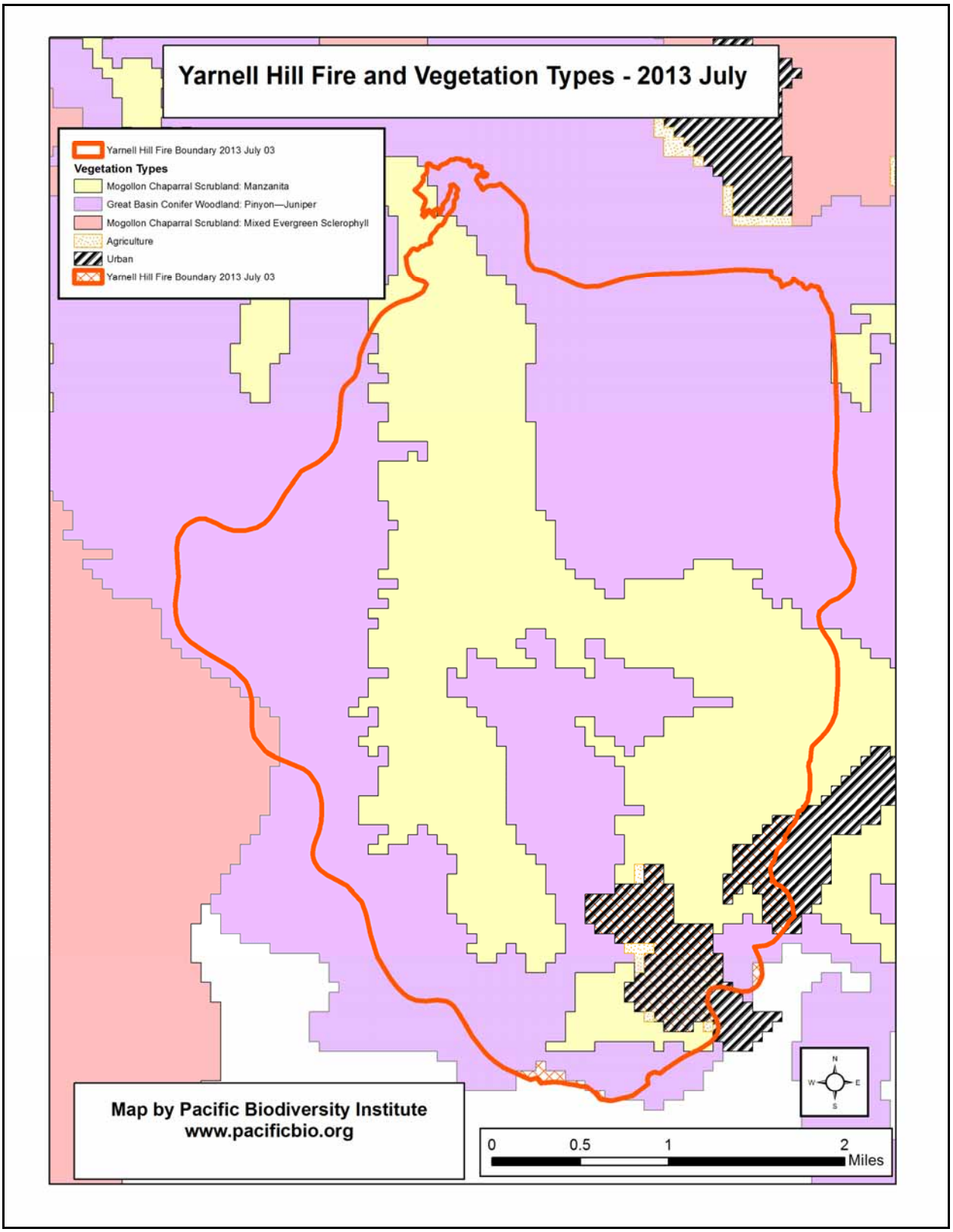
Aerial image of the ridgeline and associated vegetation near where the fire started. The terrain is rugged boulders and dense shrubby vegetation. (Image from 2011, courtesy of Google Earth)**.**

The Yarnell Hill fire is also typical of many wildfires that burn throughout the United States. In our previous studies of wildfires burning in the country, we found that in many years, most wildfires burned in chaparral, shrublands and grasslands, not in forests (Morrison et al 2000 and 2001). In 2001 our study showed that all of the largest fires (over 50,000 acres) burned primarily in deserts, grasslands and shrublands. There is a common misperception that wildfires are all forest fires. The Yarnell Hill fire and a careful analysis of the national fire situation suggests otherwise.

Aerial image of part of the Glen Ilah, west of Yarnell, burned by the fire. Note the flammable vegetation touching and often covering parts of many houses and other structures. (Image from 2011, courtesy of Google Earth)**.**



Aerial image of the valley, west of Glen Ilah where the 19 firefighters died. Note the dense chaparral brush throughout much of the valley. (Image from 2011, courtesy of Google Earth).



Vegetation type map of the Yarnell Hill Fire. Data from Arizona Gap Program. See Appendix 1 for detailed descriptions of vegetation types. Note that the pinyon-juniper woodland included in this map is still dominated by interior chaparral species with some juniper and essentially no pinyon species.

Environmentalists have not stopped the federal government from thinning and clearing up brush in the area

Since most of the land burned in the Yarnell Hill fire is privately owned land, the responsibility for managing that land would fall on the landowners. On the state land portion of the fire area, the state would hold responsibility. It is unclear if there are any state regulations requiring fire-safe management of private lands.

We have found no evidence that environmentalists discouraged any government agency from thinning and clearing the brush in this area. As Karen Klein, noted in an opinion piece contributed to the Los Angeles Times, "As yet, there is no evidence that the ferocity of the blaze that killed 19 highly trained and dedicated firefighters in Arizona was the result of a failure to thin forests by cutting down trees to create more space between those that remain..." The process for approving prescribed burns, thinning or brush clearing does not exist on private or state land in Arizona, therefore there is no way for environmentalists to even interact with these decision-making processes. The decisions are entirely determined by the land owner.

Pacific Biodiversity Institute conducted a series of studies of the landscape condition and prior land management activities for areas burned by major wildfires during the 2000 to 2003 period (Morrison et al. 2000, 2001, Harma and Morrison 2003a, Harma and Morrison 2003b, Morrison and Harma 2002). We found that many of the large wildfires burned extensive areas that had been subjected to intensive forest management activities. There was no indication that intensive forest management slowed the progression of wildfires. In fact, often the opposite was true. The 2002 Biscuit Fire in Oregon burned most intensely in previously logged areas (Harma and Morrison 2003b). The 2000 Valley/Skalkaho Fire Complex in Montana also burned most intensely in previously logged areas (Morrison et al 2000).

Most notably, the 2002 Rodeo-Chediski Fire Complex (the largest historical fire complex in Arizona) burned intensely through extensive areas of previously managed forests with a long history of logging and forest thinning (Morrison and Harma 2002). After that fire, some opportunistic politicians claimed that environmentalists were to blame for the damages of this large fire because they had tried to stop some forest thinning projects. In our study, we found the exact opposite situation. Most of the area burned by the fire had a long history of logging, thinning and forest road construction. There was no evidence that the previous forest management activities slowed the progression of the fire.

Previous management activities, human development and natural disturbances in the Yarnell area.

Some newspaper reports indicate that some of the area may have burned over 40 year ago. We examined historical satellite imagery from 1978 (35 years ago) and there was some indications of vegetation recovering from a recent burn. The 2013 Yarnell Hill Fire was not out of the range of variability for wildfires in the interior chaparral vegetation type, since the natural fire return interval is 50-100 years (Brooks et al 2007).

There is significant evidence that over a century of livestock grazing and fire suppression in areas now dominated by interior chaparral have altered the composition and structure of these plant communities (Brooks et al 2007). "Many lower elevation interior chaparral sites have been managed for livestock grazing since the 1880s (Pase and Brown 1994). Where fire was used to maintain grass forage, interior chaparral probably did not encroach into lower elevation grasslands. However, where fire was not used, and the removal of fine fuels by livestock grazing and fire suppression further decreased the frequency of wildfire, interior chaparral very

likely did encroach into lower elevation grasslands. Large areas near the early settlements of Prescott and Globe, AZ, were reported to be grasslands in the 1860s and became dense stands of interior chaparral by 1936 (Cable 1975). Aldo Leopold (1924) reported a substantial increase in “brush” cover since the 1880s at the expense of herbaceous plant cover after 40 years of livestock grazing."

"Aldo Leopold made additional observations at the interior chaparral–grassland ecotone in southern Arizona, which sheds some light on the pre-settlement fire regime of this region. He noted during the early 1920s that there were multiple fire scars on ancient juniper stumps embedded in even-aged chaparral stands consisting of shrubs <40 years old. This suggests that the fire scars were created during low intensity grassland fires that pre-dated the current chaparral stands (Leopold 1924). Based on observations such as these, Leopold concluded that there had been no widespread fires in the chaparral–grassland ecotone in southern Arizona between the early 1880s and early 1920s. He further hypothesized that previous grassland fires at these same sites occurred at intervals of approximately once every 10 years before the advent of widespread livestock grazing." (Brooks et al 2007).

Recent aerial photography (2011) reveals that there are many roads and other human incursions in most parts of the fire area. There is a dirt road along the ridge crest of Yarnell Hill to very near where the fire started. See aerial image below.

Google Earth image of the area where the fire started showing a network of dirt roads throughout the fire area and a road to very near where the fire supposedly started.

A substantial part of the fire area is composed of residential neighborhoods which have expanded in the last 40 years into the chaparral hills. See image below.

A pre-fire (2011) Google Earth image of the communities of Glen Ilah and southwestern Yarnell which burned in the fire.

Description of the area where the hotshot crew made their last stand

The 19 firefighters had been deployed in a confined mountainous valley west of Yarnell and Glen Ilah when they died. An aerial photo of that area is included in an earlier section of this report. The valley was filled with dense and very flammable chaparral brush that was tinder-dry. This part of Arizona has experienced nearly a decade of drought, which contributed significantly to the flammability of the vegetation. According to news reports, the last time a wildfire burned through this area was over 40 years ago. The Yarnell Hill Fire was well within the natural fire return interval (30 to 100 years) for the interior chaparral vegetation type.

Below we include a post-fire photo taken by the Prescott Fire Department of the valley where the firefighters died and a reconstructed pre-fire view of the valley that we made using Google Earth's 3D visualization capabilities. In the post-fire photo, it is apparent that the fire was so intense that it consumed nearly all the existing vegetation.

PBI made this reconstruction of the valley where the 19 firefighters died using Google Earth's 3D imaging capability. This pre-fire aerial image shows the dense and highly flammable chaparral brush that filled the valley prior to the fire. Compare this to the post fire image below.

This aerial photo provided by Prescott Fire Department, taken Thursday, July 4, 2013, shows the site where 19 firefighters were killed in an Arizona wildfire on Sunday, June 30, 2013. The line in the middle of the photo, built by a bulldozer after the deaths, allowed law enforcement and fellow firefighters to reach the fallen firefighters and remove their bodies from the mountain the day after they were killed. The Prescott Fire Department identified the site where the men died as the discolored patch of earth just beyond where the bulldozer line ends. The photo also shows that the intense wildfire wiped out all vegetation in the area. (AP Photo/Prescott Fire Department)

Drought, Fire Weather and Fire Behavior Modeling

Very low fuel moisture due to a long-term drought and the preceding days of high temperatures and lots of sunshine created very hazardous conditions for the Yarnell Hill Fire. This was greatly compounded by the most important factor in wildfire behavior: the current weather conditions of humidity, temperature and wind speed. During the first several days of the fire, the temperatures exceeded 90 °F. and often exceeded 100 °F. The winds were often above 20 mph with gusts as high as 43 mph. These are extreme and very dangerous fire weather conditions.

Ten Year Regional Drought

This fire situation was first set up by a ten-year regional drought. Long-term droughts create highly stressed, very flammable vegetation with very little water content. Such vegetation ignites very easily and fire can then spread quickly at a high intensity.

Fire Weather Situation During the Fire

As Bill Gabbert posted in Wildfire Today, about the Yarnell Hill Fire, on June 30, 2013: "From 10 a.m. until 4 p.m. local time at the Stanton RAWS weather station four miles south of the fire, the wind was from the south-southwest or southwest, but at 5 p.m. it began blowing from the

north-northeast at 22 to 26 mph gusting up to 43 mph. This may have pushed the fire into the town."

The table below, from a RAWS weather station near Yarnell, illustrates the problem.

RAWS data through June 30, 2013 - 23:01 back through June 28, 2013 - 23:01 MST

Time(MST)	Temperature	Dew Point	Relative Humidity	Wind Speed	Wind Gust	Wind Direction	Quality check	Solar Radiation
	° F	° F	%	mph	mph			W/m*m
23:01	90	43.5	20	6	9	N	OK	1
22:01	92	42.4	18	4	5	N	OK	0
21:01	95	41.7	16	3	8	SW	OK	1
20:01	98	40.6	14	10	17	SSW	OK	30
19:01	101	39	12	10	20	SSW	OK	231
18:01	103	38.3	11	12	22	SSW	OK	453
17:01	104	36.6	10	13	22	SSW	OK	684
16:01	106	35.5	9	13	22	SSW	OK	885
15:01	105	34.7	9	12	23	SSW	OK	1047
14:01	106	35.5	9	12	23	SSW	OK	1124
13:01	106	35.5	9	12	28	SSE	OK	1114
12:01	104	34	9	17	27	S	OK	1054
11:01	103	35.9	10	12	22	S	OK	781
10:01	103	38.3	11	12	22	SSE	OK	776
9:01	102	35.1	10	8	16	ESE	OK	598
8:01	96	35.2	12	9	13	ESE	OK	176
7:01	94	39.3	15	3	9	NE	OK	109
6:01	91	38.5	16	6	19	N	OK	9
5:01	90	37.7	16	15	19	NNE	OK	1
4:01	94	37.5	14	4	18	NNE	OK	0
3:01	96	37.2	13	9	16	E	OK	1
2:01	93	38.5	15	11	19	NNE	OK	0
1:01	94	40.9	16	11	18	NE	OK	0
0:01	95	40.1	15	13	21	ENE	OK	0
23:01	92	37.7	15	11	17	NNE	OK	0
22:01	95	36.4	13	9	24	NNE	OK	0
21:01	98	36.7	12	11	20	ENE	OK	1
20:01	96	37.2	13	16	19	NNE	OK	19
19:01	96	42.5	16	17	38	NNE	OK	94
18:01	98	42.4	15	28	43	NNE	OK	290
17:01	107	33.2	8	8	19	S	OK	732
16:01	107	36.2	9	10	26	SW	OK	932
15:01	107	36.2	9	13	25	SSW	OK	1062
14:01	105	34.7	9	13	25	SSW	OK	1110

13:01	104	36.6	10	10	25	SSW	OK	1136
12:01	103	38.3	11	11	20	SSW	OK	1089
11:01	103	35.9	10	9	21	SSW	OK	978
10:01	101	36.8	11	4	12	WSW	OK	803
9:01	99	37.5	12	4	16	ESE	OK	589
8:01	97	38	13	13	19	NNE	OK	359
7:01	92	34.1	13	12	16	NNE	OK	114
6:01	88	34.5	15	8	14	N	OK	13
5:01	87	33.7	15	9	12	NNW	OK	0
4:01	86	34.6	16	4	13	WNW	OK	0
3:01	88	34.5	15	9	17	N	OK	0
2:01	88	36.2	16	11	19	N	OK	0
1:01	88	36.2	16	11	17	N	OK	0
0:01	88	34.5	15	10	15	N	OK	0
23:01	88	24.6	10	9	15	N	OK	0

The weather conditions from the beginning of the fire through the day that the 19 firefighters died (June 30) should have been a strong warning that extreme caution was needed in fighting this fire. These weather conditions also contributed significantly to the destructive effect the fire had on the native chaparral vegetation as evidenced in the post-fire photography. These conditions contributed significantly to intensity of the fire as it burned through Glen Ilah and Yarnell destroying homes.

The need to use fire behavior modeling when fighting wildfires

In the modern world, nearly all federal and most state firefighting agencies use fire modeling tools to predict the behavior of wildfires. Fire behavior modeling is an advanced science with many highly sophisticated tools that allow fire managers to predict the behavior of wildfires. Most fire behavior modelers would have immediately noticed a huge problem with the dense, highly flammable fuels present across the landscape in the Yarnell mountains and the extreme fire weather conditions. Firefighters are trained to follow the ten standard fire orders that include always knowing the weather and predicted fire behavior. The fact that the fire grew out of control was predictable. Unfortunately, it appears that insufficient attention was placed on the critical warning signals of extreme fire weather and fuel conditions, leading to an unfortunate loss of lives.

The agencies responsible for fighting wildfire at all levels of government need to avail themselves of the advanced knowledge developed by decades of fire behavior research. Real-time fire behavior modeling is one of the best ways to save lives and greatly reduce the costs of fighting wildfires.

Factors causing the fire to burn hot and destructively

Several factors led the Yarnell Hill fire to burn exceptionally hot. First, intense wildfires are the norm for the interior chaparral vegetation type. Second, it occurred during extreme fire weather and an unusually hot weather event as described above. Weather events like this are becoming more common because of global climate change. Third, the chaparral brush was very dense and tinder-dry due to long-term drought, days of intense sunshine, high temperatures and persistent winds.

As stated above, interior chaparral is notorious for burning in extremely intense fires (Brooks et al 2007). It can be very difficult to prevent and control such fires. The most practical way for our current society to deal with this situation is to design and maintain human communities that are adapted to this kind of fire environment. Construction of buildings with non-flammable materials and maintenance of depleted fuel buffer zones around buildings and at the edge of communities may be the only practical solution to life in the interior chaparral zone and similar fire environments.

Many people have advocated more mechanical thinning and brush clearing to reduce fuels in situations like this. While these fuel reduction techniques may be warranted around homes and at the edge of communities, it would be exorbitantly expensive to apply them throughout the back country. Unlike timber sales of commercially valuable timber, thinning of brush is very costly, and there is no valuable marketable product as a result to provide an economic incentive. Brush clearing in an area like the Yarnell Hill Fire would not generate any revenue. The other question in situations like this is who should bear the costs? Most of the land that was in need of fuel treatment in the Yarnell Hill Fire was private land. Should taxpayers pay for the cost of tidy management of private land, or should that be the responsibility of the land owners?

Can we hope to effectively fight wildfires like the Yarnell Hill Fire?

The Yarnell Hill Fire was an example of a wildfire that was impossible to stop with manual fire control methods, once it grew beyond a few dozen acres in size. The combination of dense brush, very low fuel moisture, very high temperatures and very high, gusty winds created a situation that was beyond human capabilities to control. Wildfire can be an incredibly powerful force, equivalent or exceeding the energy released by large nuclear weapons.

Seasoned wildfire fighters and wildfire experts know that there are many times when the only sane thing to do is to retreat. The communities of Yarnell and Glen Ilah should have been evacuated, as they were. Some use of air tankers to drop fire retardant in strategic locations probably helped save some homes. But placement of ground crews in situations like this is futile. There is really nothing that they could do to counter the incredible energy and force of the Yarnell Hill Fire. Following the ten standard fire orders and making use of real-time fire behavior modeling can alert fire managers of extreme fire conditions where ground forces are not appropriate.

Analysis of potentially fire-safe structures in the Yarnell Hill Fire area

PBI conducted a rapid assessment of homes and other structures inside the southeast perimeter of the Yarnell Hill Fire to determine how many structures had tree and shrub canopies touching them or overlapping their roofs. We used Google Earth to do that assessment. This analysis gave us a preliminary estimate of the number of potentially fire-safe homes and other major structures (see images below).

Google Earth image of residences inside the Yarnell Hill Fire perimeter. Images were zoomed and structures ranked as potentially fire-safe were flagged with colored dots (see description of method below).

We defined potentially fire-safe structures as buildings not in contact with trees, shrubs or foliage that could act as fuel. Structures were defined as homes that could be lived in, evidenced by driveways and yards, commercial or industrial buildings or major outbuildings and major storage sheds. It was not possible in our analysis to assess the building materials used in the construction of the structures. The materials and methods used in home construction are the most important dimension of creating a fire-safe home. However, it is also very important to maintain homes in environments like the Yarnell Mountains so that flammable vegetation does not contact the home and so that the vegetation is maintained at a sufficient distance so that the heat from a fire burning that vegetation will not ignite the structure. Examples of potentially fire-safe structures are shown in below.

Example of a potentially fire-safe structure. This residence at the western edge of Glen Ilah has at least some space around the home without significant flammable vegetation. However, the distance to some small trees and shrubs is less than 15 feet in some situations.

Example of defensible residences. These home and buildings at the western edge of Glen Ilah have at least some space around the home without significant flammable vegetation. However, the distance to some small trees and shrubs is only about 25 feet in some situations.

Examples of structures that were likely not fire-safe are shown below.

Example of residences that were ranked likely not to be fire safe. All of these residences are in contact with vegetation that could act as fuel and spread fire to the house. Vegetation is green colored. Green circular areas that overlap the outline of the house are trees above the roof. All of these houses except the one in the lower right have trees above the roof, ranking them likely not to be fire safe. The house on the lower right has shrubs against the wall of the house, making it likely not to be fire safe as well.

The zoom and pan controls of Google Earth were used to view the details of vegetation in the aerial images. Potentially fire-safe structures were marked by placing a colored dot at that point on the image. After ranking all of the structures this way, the percentage of potentially fire-safe structures was determined by dividing the count by the total number of residences and multiplying by 100.

The results of our rapid assessment indicates that approximately 560 major structures were counted within the southeast perimeter of the Yarnell Hill Fire. Of these, only 63 (11%) were identified as potentially fire-safe by virtue of not being in contact with trees or shrubs.

Comparison of Potentially Fire-Safe Structures to Homes that Burned in the Fire

On Tuesday, July 16, 2013, we obtained preliminary data on structures at 115 addresses in the unincorporated communities of Yarnell and Glen Ilah that were lost in the Yarnell Hill Fire. This data was compiled by Yavapai County from assessor records and maps (and provide to us by the staff of the Arizona Republic). The list of homes and structures burned may not be complete

as investigators are continuing to canvas the neighborhoods. Most of the structures were homes, but at least three were garages or other outbuildings.

After obtaining data on the locations of the houses that burned during the fire, we compared those locations to the locations of structures that we had previously determined to be potentially fire-safe due to the absence of significant flammable vegetation in close proximity to the structure. From a quick assessment, it appears that nearly all of the houses that we determined to be potentially fire safe survived the fire without any significant damage.

There were some minor complexities related to comparing the data we developed on potentially fire-safe structures with the location data on the homes that burned. The data on homes that burned are street addresses and their point locations lie at the edge of the street - not attached to the homes or other structures. The data we developed for each potentially fire-safe structure is a point location on top of the structure in the aerial image, not the street address. So the two datasets do not overlay exactly and in some cases, it is somewhat ambiguous which structure the street address refers to and if it was one we determined might be fire-safe. However, the level of ambiguity is very low. From examination of the two datasets, it appears that perhaps three of the homes we determined to be potentially fire-safe did burn in the fire. This means that less than 5% of the potentially fire-safe homes burned and at least 95% survived the fire.

In contrast to the 5% of the potentially fire-safe homes that burned, it appears that approximately 30% of the non-fire safe structures that PBI identified using pre-burn aerial imagery did burn in the fire. The contrast between these two structure survival rates is substantial and illustrates that simple and inexpensive measures like keeping flammable vegetation away from homes can significantly increase the odds of a home surviving a wildfire.

There were also many homes that survived the fire that we determined might not be fire safe. There are many explanations for this. They may have been built using fire-retardant building materials and using of fire-safe construction techniques. Vegetation around houses that we observed in aerial images taken prior to the fire may have been cleared after the date of the aerial imagery. Another possibility is that firefighting efforts could have kept the fire from burning those homes. There may have been air drops of fire retardant on the residential neighborhoods. And wildfires tend to be spotty and haphazard when burning in residential neighborhoods. The question for homeowners is - do you want to let your home's survival be left up to a role of the dice?

Based on our quick assessment of structures and their relationship to the pre-fire environment it is no surprise that over 100 homes burned in this fire. The communities of Yarnell and Glen Ilah were not fire-safe prior to the fire. Many similar situations exist across the USA. Until we have the foresight and do the work needed to create fire-adapted, fire-safe homes and communities, the tragedy of Yarnell Hill will repeat itself many times in the future. Communities that exist in fire environments like Yarnell Hill will always be at significant risk to wildfire just as homes that are built in a river's floodplain are at risk of periodic flooding.

Preventing fire tragedies in the future demands fire-adapted communities

Tragedies like the Yarnell Hill Fire are preventable. There are some simple things homeowners can do to avoid having fires burn into our communities and homes and to prevent firefighter deaths.

First, we must be more conscientious about where and how we build. In a July 5, 2013 article, Felicity Barringer reported that 98.5 million people lived in 43.7 million homes in what is known as the “wildland-urban interface” in 2010. As Crystal A. Kolden, fire ecologist and former U.S. Forest Service firefighter, reported, “More than a million new homes were built in high fire danger areas in California, Oregon and Washington since 1990.” New construction within the wildlands urban interface should be cognizant of high fire risk and sited and constructed accordingly. Just as federal, state and local agencies have recognized the inherent danger and great expense of building in a flood plane, states and counties should rank areas by risk of wildfire and discourage building in high risk areas.

The Yarnell Hill Fire was a classic example of a wildfire that burned into a community that had rapidly expanded into high fire danger chaparral covered hills during the last 40 years.

Secondly, we can create small buffer areas around homes and communities that are relatively free of dry grass, brush and other flammable items that can carry a fire. When we do build our homes and other structures in vulnerable areas, like Yarnell and much of the western USA, they should minimize susceptibility to wildfires. Existing structures should create defensible space and fire-wise their homes with fire-proof building materials and methods. As Kolden prescribes, “Towns reluctant to support vegetation-reduction projects must reverse course and become fire-adapted communities.” We don't have to log the wilderness or “pave the planet” to save our homes. It is a relatively easy job to create fire-adapted communities and fire-adapted homes that can withstand wildfires without the need to put firefighters’ lives at risk.

Thirdly, our focus should shift from fire suppression to fire adaptation. Our national, state and local government agencies currently spend billions of dollars every year trying to fight wildfires - often with little success. Using this money to help homeowners and communities create fire-adapted homes and defensible spaces around the community would be a much wiser use of our tax dollars.

As Kolden advises, “Fire agencies need to stop using outdated suppression tactics that are too dangerous for more intense fires that burn in more extreme weather amid more houses.”

Most importantly, to prevent a tragedy like the 19 deaths that occurred on the Yarnell Hill Fire, citizens and elected officials need to be much more careful about deploying firefighters in extremely hazardous situations where they are risking their lives to protect property. As Tim Gaynor of Reuters reported, Rick McKenzie, a bow hunter and ranch caretaker, saw the fire explode "with flames 30 to 40 feet high racing across an area of oak and brush and that he had warned the Hotshots about the dense oak woods where they would be working. 'I said, ‘If this fire sweeps down the mountain to the lower hills where all this thick brush is, it's going to blow up, guys, you need to watch it,'' said McKenzie. The hazards of being on the ground in the thick, dry chaparral at the time of the fire was obvious to a member of the general public.

There needs to be a thorough, independent investigation of all the factors that contributed to this tragedy. The rational and wisdom of deploying of a hotshot crew in this chaparral covered valley during extreme fire weather needs to be addressed by this investigation.

Tragically, the hotshot crew did not have a chance once the fire exploded. The explosion of this fire, given the extremely hot weather and dense, dry brush and grass was entirely predictable. These natural forces are much, much stronger than anything we have to fight them. We need

to learn not to put young men and women in situations like this where they have little hope of survival.

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Appendix 1. Descriptions of Vegetation described in Arizona GAP vegetation data.

Mogollon Chaparral Scrubland: Manzanita
Nearctic Upland, Warm Temperate Scrubland, Mogollon Chaparral, Manzanita Series (1133.q0a1)

Distribution: Widely distributed between 1,250 and 2,590-m elevation. It occurs on non-calcareous soils from Grand Canyon National Park in northwest Arizona to the Chiricahua Mountains in the southeast. The series abuts the Encinal (1123.t0a1) or Pinyon-Juniper Series (1123.l0a0). The Manzanita Series is successional, often forming extensive, nearly pure, stands within Encinal and Pinyon-Juniper Woodland Associations. Such stands appear to be very slowly replaced with tree-dominated vegetation although manzanita remnants seem to never completely disappear.

Physiognomy: Unevenly distributed evergreen sclerophyll shrubs 0.9–1.8-m tall. 1Grasses usually present in openings between shrub clumps. Total vegetation cover is 50–80 percent.

Floristics: *Arctostaphylos patula, A. pringlei, A. pungens, A. uva-ursi* are the most prominent shrubs with *A. pungens* most usually found. *Quercus turbinella, Garrya flavescens, Glossopetalon spinescens* var. *nevadense, Cercocarpus montanus, Yucca baccata, Rhus trilobata,* and *Agave utahensis* are often present in small numbers. *Aristida purpurea* var. *fendleriana*, *A. orcuttiana*, *Bouteloua aristidoides*, *B. curtipendula*, and *Stipa neomexicana* are grasses commonly occurring in scrub openings.

Diagnostic characteristics: Manzanita, usually *Arctostaphylos pungens*, is dominant and tends to occur in nearly pure stands but may be mixed with other chaparral species such as *Quercus turbinella* and *Cercocarpus montanus.*

Great Basin Conifer Woodland: Pinyon—Juniper
Nearctic Upland, Cold Temperate Forest and Woodland, Great Basin Conifer Woodland, Pinyon—Juniper Series (1122.l0a0)

Distribution:
Elevation range is between 1,220 and 2,130 m. Wide ecological amplitude of the dominant tree species and high diversity permits this series to develop on a wide variety of sites. Sites range from slick rock, to gravelly shallow soils, to steep slopes. The soils are always well - drained and are usually shallow and not acidic. Fuel loading is generally too light to carry ground fire. Although these communities do burn, high winds are necessary to carry the flames from plant to plant.

Physiognomy:
Evergreen needleleaf woodland of mesophanerophyte or microphanerophyte trees. Tree crowns are round to oval in shape. Trunks may be nearly unbranched or formed from a forked trunk. Even moderate snow loading breaks down broad-crowned trees, but oval-shaped crowns are more resistant to damage. Tree heights are between 4.6 and 9.2 m. The understory of these communities is composed of sclerophyllous evergreen, or gray-green evergreen shrubs 0.9–1.8 m in height. Half-shrubs are present and important on more xeric sites. Perennial grasses are not prominent. Total cover ranges between 10 and 50 percent.

Floristics:
Pinus edulis edulis, P. edulis fallax, P. monophylla, Juniperus osteosperma, J. monosperma, J. deppeana, J. scopulorum, and J. erythrocarpa dominate the community. The pines are codominant and unlike the junipers, rarely, if ever, form pure stands. Other species character istic of the Pinyon—Juniper are Quercus turbinella, Q. x pauciloba, Ephedra viridis, Ceanothus intricatus, Gutierrezia sarothrae, Cercocarpus greggii, Yucca baccata, Artemisia tridentata, Purshia mexicana, and Bouteloua gracilis.

Mogollon Chaparral Scrubland: Mixed Evergreen Sclerophyll Nearctic Upland, Warm Temperate Scrubland, Mogollon Chaparral, Mixed Evergreen Sclerophyll Series (1133.q0a5)

Distribution: Widely distributed, occurring on non-calcareous soils from Grand Canyon National Park in northwest Arizona to the Chiricahua Mountains in the southeast. Elevation range is between 1,250 and 2,590 m. The series abuts the Encinal (1123.t0a1----) or Pinyon-Juniper Series (1123.l0a0----). Particularly fine stands are found in the Bradshaw Mountains and associated ranges. This series contains plants which rarely occur in pure stands. The *Ceanothus-Cercocarpus* elements appear to be favored in limestone -derived soils while the evergreen oak woodland is confined to rhyolite-derived soils. Although this vegetation may be a fire disclimax, none of the inhabitants are particularly flammable. *Quercus toumeyi* responds to burning by crown sprouting and *Arctostaphylos, Ceanothus,* and *Cercocarpus* produce seed which seldom germinate without being fire scarified.

Physiognomy: Evergreen broadleaf sclerophyll scrub. These particular plants have limited amounts of oils and waxes (< 4.5 percent) and are thus less flammable than their more famous analogues in the California Chaparral. Where moisture permits and deep soils are present, dense scrub typically covers 70–85 percent of the ground.

Floristics: At least 3 broadleaf sclerophyll shrubs are codominant. Some common examples are: *Ceanothus greggii, C. fendleri, Arctostaphylos pungens*, *A. pringlei*, *Rhamnus crocea, Cercocarpus montanus, Ribes quercetorum*, *Quercus toumeyi, Q. turbinella, Celtis laevigata* var*. reticulata*, and *Purshia mexicana*. In addition, *Eriogonum wrightii*, *Mimosa aculeaticarpa* var. *biuncifera*, *Calliandra eriophylla*, *Fallugia paradoxa*, *Agave parryi*, and *Dasylirion wheeleri* are less important and present in various combinations. *Pinus discolor*, *Juniperus erythrocarpa*, and *Quercus emoryi* are found scattered on sites with better moisture but never dominate the landscape. Beneath the dense canopy of mature vegetation, little herbaceous cover can be found. Where openings occur *Aristida purpurea* var*. fendleriana*, *A. orcuttiana*, *Bouteloua aristidoides*, *B. curtipendula*, and *Stipa neomexicana* are found. Ferns, particularly *Pellaea intermedia*, grow on sunny slopes in soil pockets. *Bromus rubens* and *B. tectorum* may form a patchy herb layer along with *Castilleja integra*, *Penstemon linarioides*, *Astragalus nuttallianus*, *A. nothoxys*, *A. wootonii*, and *Kallstroemia grandiflora* grow where light and space permit.

Diagnostic characteristics: This series is a catchall that gathers together the Arizona chaparral, other than those dominated by manzanita. Although the chaparral in Arizona forms a number of distinct communities, they are small, patchy, and finegrained. Most are smaller in the minimum mapping unit of 40 ha and thus must be lumped.