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Concept note:

Quantifying occurrence and carbon emissions from delayed reforestation in Californian forests following high-severity wildfire

Project:

Quantifying ecosystem service benefits of reduced occurrence of significant wildfires (2015-2019); Task 6: ‘Avoided wildfires: accounting for ecological co-benefits’

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Summary

- Delayed reforestation following high severity wildfire is occurring across multiple forest types in California at a high rate;
- Delayed reforestation is defined here if no tree-dominated vegetation cover re-establishes at least 20 years post high-severity burns;
- We analyzed FVeg data to identify high severity burns (MTBS class 4) that occurred prior to 1994 and examined what fraction of the acreage was not associated with tree cover by 2015 (FVeg);
- Results are presented by forest type and percentage of acreage affected by delayed reforestation;
- We reviewed literature to identify non-tree vegetation types commonly occurring on sites that experienced high-severity wildfires;
- Carbon stocking estimates for shrubland including potential stocks are provided by ecoregion for the Western US;
- To account for potentially undetected tree carbon in shrublands (due to tree height >1m) at year 20 post high-severity wildfire, we generated tree carbon stocking estimates up to year 40 for the Sierra Nevada range.

Date:

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1 RATIONALE

High severity fires in forests, particularly uncharacteristically severe active and passive crown fires, can cause high levels of tree mortality and soil impacts. High severity fires can result in the delayed regeneration of forest cover and a dominant vegetation of grassland or shrub types over extended periods of time (Collins & Roller, 2013; Coppoletta et al., 2016; Roccaforte et al., 2012; Rother & Veblen, 2016; Tubbesing et al., 2019; van Wagtendonk et al., 2012; Welch et al., 2016). Fuel treatments can reduce the amount of forest that is affected by delayed reforestation compared to the baseline, through moderating fire size and severity.

The goal of the analysis presented here was to provide an implementable procedure to quantify carbon loss due to delayed reforestation in California following high-severity wildfires. The research objectives were to i) quantify the risk of delayed reforestation due to high-severity fire by forest type and ii) quantify the average carbon stocking of non-forest vegetation types following high-severity wildfires.

In the context of a carbon offset protocol, this concept note provides a methodology to quantify carbon emissions from delayed reforestation over a 40-year timeline following high-severity wildfires, i.e. carbon stocks and fluxes for e.g. a forestry project have to be accounted for over 40-year time frame. Permanence is therefore restricted to a 40-year timeframe. Therefore, in the context of delayed reforestation, we equate delayed reforestation with evidence that no forest cover has reestablished after 40 years.

2 METHOD

2.1 Quantifying acreage affected by delayed reforestation using FVeg data

Step 1: Identify pre-1994 forest cover

Figure 1 outlines the three-step process identified to generate occurrence estimates of and carbon stock estimates for shrub-dominated landscapes following high-severity wildfires. For step 1, we used 1977 CALVEG to identify vegetation type classification layers (the best approximation prior to 1984) for pre-1994 forest cover in California. We used CA-GAP data to subtract non-forest tree cover such as urban parks (USGS, 2011).

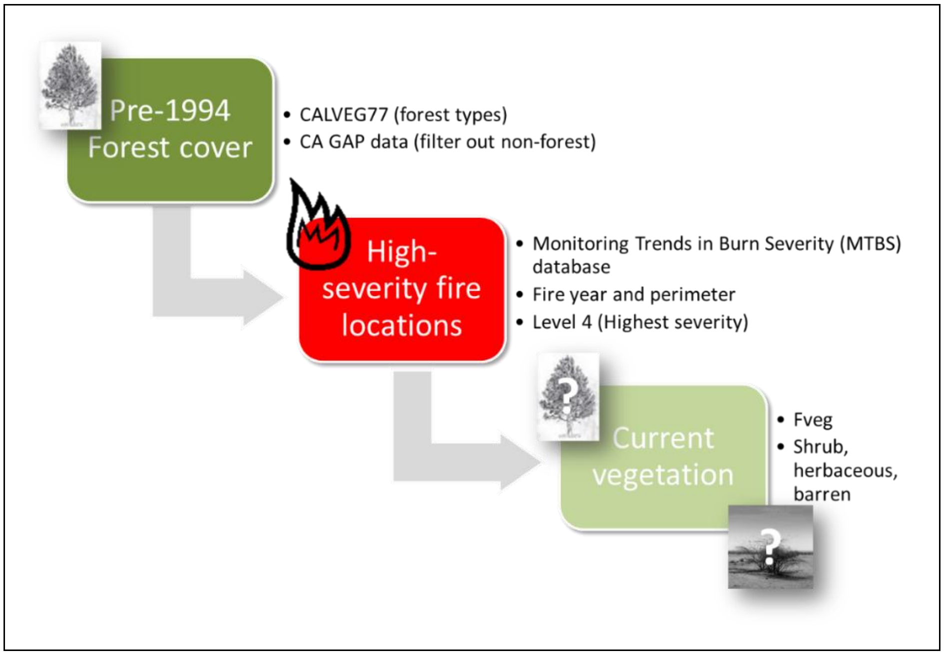

Figure 1: Steps to quantify acreage affected by delayed reforestation following high-severity wildfires.

Step 2: Identify high-severity areas

We used the 'USFS Region 5 Burn Severity Database-1984-present' (USFS, 2017) to identify the area of all wildfires since 1984 that were high severity (Burn Severity 4; i.e. lethal to the tree, Brewer et al. 2005) within California. Areas that experienced less severe fires followed by delayed regeneration (e.g. Batllori *et al.*, 2015; Gonzalez *et al.*, 2015) were therefore excluded resulting in a conservative estimate of delayed reforestation following wildfires.

Step 3: Identify delayed reforestation occurrence using FVeg data

We used 2015 FVeg data (CAL FIRE, 2015) to identify existing vegetation types as of today on the areas that burnt at high severity between 1984 and 1994 (Figure 1). The restriction to wildfires prior to 1995 should allow for a sufficient buffer of 20 years to exclude misclassification of vegetation type (i.e. absence of trees) due to ongoing natural or artificial regeneration. As a proxy for delayed reforestation, we therefore assumed that if no regeneration is detectable at least 20 years after a fire, an enduring delay in reforestation has occurred and the landscape is dominated by shrub or grassland vegetation types at least over the medium term (20-40 years).

FVeg 2015 data provides the data layer Life Form containing the following categories: Barren/Other, Conifer, Hardwood, Herbaceous, Shrub. We excluded acreage classified as Barren/Other from our analysis since lost forest cover could be caused by other drivers than wildfire severity (e.g. land use conversion towards development). Delayed reforestation (DR) as evidenced under the Life Form FVeg 2015 layer would defined as in Equation 1.

Equation 1: Percentage of delayed reforestation by forest type following high-severity wildfire in California using FVeg.

$$DR_{LifeForm} = (Herbaceous + Shrub) / (Conifer + Hardwood + Herbaceous + Shrub)$$

Where:

$DR_{LifeForm}$ Fraction of acreage affected by delayed regeneration following high-severity wildfire; percent of total acreage affected by high-severity wildfire (%)

$Herbaceous$ FVeg Lifeform typology for herbaceous-dominated ecosystems; acre (acre)

$Shrub$ FVeg Lifeform typology for shrub-dominated ecosystems; acre (acre)

$Conifer$ FVeg Lifeform typology for conifer-dominated ecosystems; acre (acre)

$Hardwood$ FVeg Lifeform typology for hardwood-dominated ecosystems; acre (acre).

2.2 Carbon stocking of non-forest vegetation types following high-severity wildfires

Shrub carbon pools

We reviewed the scientific literature on delayed reforestation relevant data for both typical non-forest vegetation types following high-severity wildfires and related carbon stocking in the Western US. A full list of the reviewed literature is attached as Appendix 1.

Tree carbon pools

Since we were only able to confirm shrub-dominated landscapes up to 20 years following a high-severity wildfire, there is a possibility that natural tree regeneration was not detected due to similar shrub and tree heights of around 1m at the end of a 20-year period. Since permanency in ACR is defined over a 40-year time horizon, it would be important to also consider potential average tree carbon stocks from year 20 to year 40 due to undetected tree growth. We used the Western FVS Variant to estimate maximum total stand carbon stock for a variety of stand types 20 years after establishment.

Soil carbon pools

Besides the life and dead carbon pool, the soil carbon pool can be significant but is relatively unaffected by fuel treatments and is excluded (Boerner et al., 2009; Kashian et al., 2006; Woodbury et al., 2007). This conservatively underestimates fuel treatment project benefits as reducing fire severity increases carbon soil through reducing erosion, reducing soil carbon vaporization, and decreasing soil respiration. For consistency, shrub vegetation-specific soil carbon estimates were therefore omitted since they are not accounted for under ACR protocol requirements. Screening the literature for a further break-down of carbon stocking by genera provided no further options to refine results.

Estimating total average carbon stocks following high-severity wildfire on shrub dominated landscapes

The maximum total stand carbon for a shrub dominated stand with tree saplings (undetected at year 20 due to limited height) between year 0 and year 40 following a high-severity wildfire would be the average total stand carbon over those 40 years and can be calculated using Equation 2.

Equation 2: Total carbon stock of shrubland including potential tree regeneration.

$$SC_{total} = (SC * 40 + TC * 20) / 40$$

Where:

SC_{total} Average total stand carbon for a shrub dominated landscape with tree regeneration between year 0 and 40 following high severity wildfire; metric tonnes (MT) CO_2 equivalent (CO_2/acre)

SC Total stand carbon of shrub dominated landscape (Table 2); metric tonnes (MT) CO_2 equivalent (CO_2/acre)

TC Total stand carbon of tree dominated landscape starting with 1 m saplings year 20-40 (Table 3); metric tonnes (MT) CO_2 equivalent (CO_2/acre).

3 RESULTS AND DISCUSSION

3.1 Acreage affected by delayed reforestation

Results suggest that delayed reforestation, i.e. the absence of a tree-dominated vegetation cover after 20 or more years after a high-severity wildfire, is pervasive across most forest vegetation types in California (Table 1). The dominant forest types in the Sierra Nevada range such as Sierran Mixed Conifer, showed delayed reforestation on 43% of the high severity burns. Of the 202,127 acres forested at the time of a wildfire and experiencing a high-severity burn, 55% experienced delayed reforestation. While results for less abundant forest types might be affected by higher uncertainties (e.g. lodgepole pine on 124 acres), results for other prominent forest types such as the Sierran Mixed Conifer, representing 20% of total acreage analyzed, can be considered robust and show a high risk of delayed reforestation following high-severity wildfires.

Table 1: Delayed reforestation as evidenced by FVeg 2015 Life Form. Forest types ordered by acreage affected by MTBS burn severity 4 between 1984 and 1994. A high percentage indicates a high fraction of the high-severity burn is not under tree cover as of 2015.

Forest type (CALVEG77 WHRNAME)	Acres burnt at high severity	Delayed reforestation (% of acreage)
Sierran Mixed Conifer	40,706	43%
Chamise-Redshank Chaparral	25,404	87%
Montane Hardwood-Conifer	15,385	45%
Douglas-Fir	15,028	34%
Coastal Oak Woodland	14,559	61%
Montane Hardwood	14,073	44%
Jeffrey Pine	13,047	78%
Klamath Mixed Conifer	12,846	52%
Ponderosa Pine	11,579	50%
Mixed Chaparral	10,075	62%
Blue Oak Woodland	8,710	50%
Eastside Pine	8,475	9%
Red Fir	4,562	79%
Pinyon-Juniper	2,057	86%
Montane Chaparral	1,846	66%
White Fir	1,512	82%
Valley Oak Woodland	1,395	77%
Juniper	648	94%
Lodgepole Pine	124	21%
Subalpine Conifer	55	5%
Redwood	43	18%
Grand Total	202,127	55%

Results could be considered to be conservative. While our methodology identified 55% of all high-severity burns being affected by delayed reforestation, Welch et al. (Welch et al., 2016) suggests a similar percentage for all burnt acreage including low- and medium-severity wildfires by stating that “In 54 percent of the areas burned this century, the research suggests too few trees grew back to ensure a full forest recovery.” Meanwhile, Shive et al. ((Shive et al., 2018) stress once more the causal relationship between high-severity burns and delayed reforestation with their research suggesting that “Annual precipitation and continuous burn severity (IA) had the largest effect on the odds of regeneration, […]”.

Our conceptual approach to identifying the risk of delayed reforestation following high-severity fires is further corroborated by California-specific Forest Service data on the ‘Threat of Deforested conditions in CA National Forests’ (USFS, 2015). This effort identifies high-severity burn patches and provides replanting recommendations based on Landfire-derived tree survival rates. The resulting maps and datasets suggest that a large fraction of stands that experienced high-severity burns should be actively replanted to ensure continuous forest cover. However, only a fraction of this acreage in need of reforestation is replanted annually. For instance, only 6% of the acreage in need of reforestation in 2015 was replanted. The corresponding average from 1986-2015 is 20%. The ‘buildup’ of the reforestation need-accomplishment gap 1986-2015 results in substantial lost carbon sequestration capacity which this concept note attempts to quantify.

3.2 Post high-severity wildfire shrub vegetation types and carbon stocking

Shrub carbon pools

Most of the identified literature focused on tree reestablishment following high-severity wildfire. Since this element of delayed reforestation was covered with the remote sensing and GIS based analysis presented above, it had less relevance for this effort. In general, the publications had only a secondary focus on the type of non-tree vegetation types. However, all studies that identified non-tree vegetation types following high-severity wildfires were consistent in reporting i) shrub rather than grass dominated vegetation types and ii) identifying Ceanothus and Arctostaphylos genera as the most common shrub types due to their fire-resilient seed banks (Collins & Roller, 2013; Goforth & Minnich, 2008; Nagel & Taylor, 2005; Zald et al., 2008). There is very limited literature Concerning carbon stocking of shrub vegetation. Zhu & Reed (2012) provided life and dead carbon stocking estimates for shrub vegetation types in the Western US as a whole as well as by ecoregion (Table 2). Battles et al. (2014) provide estimates for shrubland averaging over 1m in height in California of 13.2 Mg CO_2e/acre for above and belowground life carbon pools. In the context of a carbon estimate over a 40-year timeframe, assuming an average shrub height over 1m for shrublands of 0-40 years in age was deemed to be reasonable. Since the dead carbon pool is not quantified, this is considered to be a conservative estimate. Furthermore, the numbers provided in Table 2 assume a fully established shrubland. However, post high-severity fire shrubland establishment will accumulate carbon over time, maturing at a later stage. Accounting for shrubland carbon by using the inputs from Table 2, i.e. using a high shrubland carbon estimate instead of an average carbon estimate reflecting carbon accumulation from shrubland initiation to maturation over a 40-year timeframe, is therefore adding to a conservative carbon emission estimate of high-severity wildfires.

Table 2: Average life and dead carbon stocking (above- and belowground) of shrublands/grasslands by ecoregion in the Western US (Zhu & Reed, 2012, p. 115) based on minimum and maximum projections. Soil carbon estimates are omitted since they are not accounted for under ACR protocol requirements.

Ecoregion	Area (acres)	Live biomass (Mg CO_2e/acre)	Dead biomass (Mg CO_2e/acre)	Live & dead biomass (Mg CO_2e/acre)
Western Cordillera	678,368	5.9	7.5	13.4
Marine West Coast Forest	10,737	0.2	0.2	0.4
Cold Deserts	1,962,647	15.6	14.5	30.1
Warm Deserts	981,358	7.6	5.7	13.3
Mediterranean California	161,736	1.8	2.2	4.0
Western US	3,794,846	5.6	5.4	11.0

Tree carbon pools

In the context of a typical Eldorado area Sierra mixed conifer stand starting with 1m tall saplings and assuming at a site index of 100, the Western FVS Variant yields a maximum total stand carbon stock (above and belowground) of 36.6 Mg CO_2e/acre (black oak at 250 trees per acre) after 20 years (Table 3).

Table 3: Western FVS variant generated total stand carbon stocking estimates (CO_2e/acre) for a typical range of species and tree densities at year 20 following a sapling stage.

Saplings per acre	Black Oak	Incense Cedar	Ponderosa Pine	White Fir
10	30.9	17.4	22.6	3.1
50	26.7	30.1	24.5	28.2
100	33.3	35.3	32.1	34.4
150	7.0	11.2	4.9	9.1
200	21.7	25.4	19.6	23.7
250	36.3	27.1	31.6	13.4

Total average carbon stocks following high-severity wildfire on shrub dominated landscapes

Using input data from Table 2and Table 3 in Equation 2, the maximum average total carbon stock on shrubland post high-severity wildfire over 40 years is SC_{total}= (13.4 MT CO_2e/acre *40+36.6 MT CO_2e/acre *20) / 40 = 24.8 MT CO_2e/acre.

4 NEXT STEPS

The methodology described and tested above is promising in quantifying i) the occurrence of delayed reforestation and ii) stand carbon stocks post high-severity wildfires. If applied to areas outside of California, it would be important to use pre- and post-wildfire landcover datasets that are based on similar landcover type detection methodologies. For instance, comparing pre-wildfire CALVEG77 data with post-wildfire Landfire data instead of FVeg data entails the risk of classification mismatches. To further corroborate and refine results, we suggest the following steps:

- Individual 2015 FVeg inputs have a variety of vintage years. The current dataset could be further filtered for high-severity wildfire affected areas that star a FVeg data entry with a vintage year less than 20 years post-wildfire occurrence;
- Spot checking spatial datasets that suggest post high-severity wildfire delayed reforestation could further rule out misinterpretations;
- Extend this California-focused analysis and provide datasets by ecological supersection covering the entire western US.

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APPENDIX 1: FULL LIST OF REVIEWED LITERATURE ON DELAYED REFORESTATION IN THE WESTERN US.

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