­­Demography of Species; a comparison pre and post Fire at Pepperwood Preserve

Simple statement:

*Fire effects as a function of size, species, and fire severity*

Novelty/gaps in knowledge:

*Increase understanding of size dependent, species specific survival rates and recovery strategies in responses to wildfire*

**Title: Size-dependent mortality and species specific responses to varying degrees of fire severity in a California mixed hardwood system following the Tubbs Fire (Sonoma Co., October 2017).**

**Abstract**:

Recent years have shown increases in both frequency and intensity of wildfires in western North America as a result of accelerating climate change. In contrast to temperate coniferous forests, many species in mixed hardwood systems resprout prolifically post-fire. This leads to different survival outcomes for hardwoods with total canopy loss but vigorous basal resprouts and topkilled conifers. Resprouting combined with diverse regeneration and drought tolerance strategies create unique post-fire trajectories that require further research.

In Sonoma County, California the Tubbs Fire (Oct. 2017) burned ~13,351ha (>25% high,  >35% medium severity), including large areas of oak woodland and mixed hardwood forest. In 2018 we conducted a complete demographic resurvey of a pre-existing plot network (est. 2013) at the Pepperwood Preserve (38.57°N,-122.68°W), consisting of 54 plots (20x20m) stratified across varying topographic gradients and evenly represented by evergreen and deciduous oak sites (Oldfather 2016). All trees (dbh >1cm) and saplings ( >50cm tall, <1cm dbh) were tagged and measured, and all seedlings (<10cm) and juveniles (11-50cm) were tallied by species, both pre- and post-fire. We examined post-fire recovery in >30 species to quantify mortality, topkill (with resprouting), and crown survival in relation to pre-fire size (dbh), fire severity, and species.

Fire severity was assessed using satellite-based remote sensing metrics and correlated with post-fire assessments of canopy damage in the field. Best-fit logistic models for post-fire status (dead, topkill, live-crown) included size, fire severity, species identification, and ‘sizeXseverity’ or ‘sizeXspecies’ interactions. Topkill rates are unimodal in relation to size, with higher mortality at small sizes and higher crown survival for larger trees. In both high and moderate severity fire California bay, madrone, coast live oak and black oak exhibited high levels of topkill combined with basal resprouting. Douglas-fir, which lacks the ability to resprout, exhibited the highest mortality, particularly saplings in high severity. D50, the critical size to achieve 50% survival, ranged from <1cm to >15cm across species, on average, and decreased with fire severity, with the highest values for thinner bark species.

These results suggest that stands dominated by resprouting hardwoods are on a trajectory to return to pre-fire conditions, more so than Douglas-fir dominated sites, where there is potential for type conversion or invasion as understory species resprout-an important implication with regard to Douglas-fir encroachment. Quantification of post-fire responses, coupled with knowledge of drought-tolerance, will help project the impacts of future climate change and wildfire on these systems.

**Introduction**:

*Outline for intro*

*-Set up fire/climate change in the region – need for investigation*

*-Introduce pepperwood network as a baseline for changes to forest structure in the face of climate change and disturbance. Describe Tubbs fire and conditions that led to it.*

*-Describe overall setting/ species/ climate/ fire history at PWD*

*-Introduce resprouts/ lack of info in Ca- need for study*

*-Set up out 3 outcomes/ 4 fates and goals to determine rates of each based on species and size*

*-Take home message/ final paragraph of intro*

***Introduce effects of Climate change and disturbance, higher annual temps, less rainfall and more frequent fires in the study area:***

In recent years, wildfires in the American west, specifically California have intensified in both size and frequency due to the prolonged effects of drought and increasing temperature. (*something about these factors contributing to greater fuel loads*) Stand replacing fires can lead to changes in forest structure over time (*add more components of grant proposal here*)

Using a plot network established in 2013 as part of the Pepperwood Forest Dynamics Project, where woody community diversity and topoclimate had already been quantified (Oldfather 2016) – (talk of topoclimate/ hydrologic and topographic gradients here). in order to monitor long term forest dynamics and quantify changes in stand structure and species composition in response to climate change and disturbance using baseline data. Plots were stratified across varying topographic and hydrologic gradients and evenly represented by evergreen and deciduous oak sites (Oldfather 2016).

***Describe the overall setting:***

The location is a Mediterranean climate, oak woodland, mixed hardwood with one dominant conifer species. Then dominant species. The most abundant species include three species of deciduous oaks (*Quercus garryana, Quercus kelloggii, Quercus douglasii*) and one evergreen oak *(Quercus agrifolia),* twomixed hardwoods *(Umbellularia californica, Arbutus menziesii),* twolarge woody shrubs *(Arctostaphylos manzanita, Heteromeles arbutifolia)* and one conifer species *(Pseudotsuga menziesii).* Secondary species include.. list here or refer to supplemental

Describe the climate, rainfall averages, minimum and maximum temps... Then focus on Pepperwood- size and location. 1263 ha Pepperwood Preserve in Northern California, just east of the city of Santa Rosa (Sonoma County Ca, 38.57°N,-122.68°W). Describe the historic fire intervals, Hendley in 1964 (Two large fires on the preserve in 1964 and 1965, and no other fire have occurred since that time (Halbur et al.2013)) until Tubbs in October of 2017 followed the same path. Talk about high wind event, path of Tubbs night one, high intensity burning over 85% of the preserve followed by several days of moderate to low intensity fire….Then introduce the increased frequency of fire interval – Kincade fire November 2019, that burned form the opposite direction. Discuss native history of prescribed burns and subsequent century of fire suppression

Historically studies on fire have been performed in conifer stands without an abundance of resprouting hardwoods, leaving little to no information on fires in the coastal oak woodlands of the west, specifically in mixed evergreen-deciduous woodlands of Northern California where resprouting hardwoods contribute significantly to forest structure. (JG Pausas lit review )

Resprouting as a survival strategy for fire adapted species occurring within California oak woodlands and within Mediterranean ecosystems in general, as a method of resilience/resistance to fire.

Introduce the 4 outcomes nested within 3 fates post-fire…

Fates

1. Dead (total canopy loss, no basal resprouts)
2. Topkilled (total canopy loss, with basal resprouts)
3. Crown survival (canopy survival, with or without resprouts)

Outcomes

1. DN mortality
2. DR topkilled with resprouts
3. LN live (green crown, no resprouts)
4. LR live (green crown with resprouts)

***Last paragraph:***

In this study we aim to determine the size dependent, species specific rates of mortality, topkill, and crown survival across a fire gradient from low to high-severity, and determine how responses differ between saplings and trees for the dominant tree species present within the PWD forest dynamics plot network. We do this in order to increase understanding of post fire survival / recovery strategies for some of the most abundant woody species in California oak woodlands.

**Methods**:

***Field Surveys:***

In 2013 a network of forest research plots was installed at the 1263 ha Pepperwood Preserve in Northern California, just east of the city of Santa Rosa (Sonoma County Ca, 38.57°N,-122.68°W) within a coastal mixed hardwood forest in order to monitor long term forest dynamics in response to climate change and disturbance. The network consisting of 54 plots (20x20m) was stratified across varying topographic and hydrologic gradients and evenly represented by evergreen and deciduous oak sites (Oldfather 2016). All individual trees or shrubs with a minimum 1cm diameter at breast height (DBH), and saplings taller that 50cm but <1cm DBH were tagged with a permanent unique identification number. Additionally all seedlings (<10cm tall) and juveniles (>10cm <50cm tall) were tallied by species both pre- and post-fire. For saplings we measured the height of each individual, the basal diameter (at 10cm) of the main (largest) stem, and indicated the number of additional stems branching off below 10cm. For trees, diameter of the main stem was measured at 1.4m and was recorded for each additional stem that branched off the main stem below breast height. These measurements were later used to calculate basal area per tagged individual.

Following the Tubbs fire a full demographic resurvey was completed in 2018 and growth measurements were recorded for all individuals that remained from the 2013 survey. All new recruits were tagged and measured following the original 2013 protocols. Whenever possible diameter measurements were taken on the same stem and at the same location to capture growth data, regardless of an individual stems fate post fire. The only group of individuals not measured were new recruits that were killed in the fire with no stems remaining. If evidence of a dead untagged individual remined they were measured but not tagged. This group of unmeasured individuals was likely only a very small number of saplings. Four new plots were installed in 2018 to account for the underrepresentation of plots in the highest severity burn zone and dead individuals, while not tagged, were included in measurements to best determine pre fire biomass.

For trees, each individual stem, and each individual sapling were then categorized based on canopy survival and the presence or absence of basal resprouts. Prescence of any surviving canopy indicated the individual was alive and had survived the fire. The amount of “green crown” remaining was then recorded by assigning a category based on percentage of living canopy 0-5 (1. <5%; 2. 6-33%; 3. 34-66%; 4. 67-94%; 5. >95%) and the presence or absence of basal resprouts was noted. If there was no canopy survival, but basal resprouts were present the individual was categorized as alive and “topkilled”. In the event of total canopy loss and absence of basal resprouts the individual was categorized as “dead”. If an individual was top-killed and resprouting from the base, then the number of basal resprouts over 50cm tall (sapling criteria) were tallied, and the height of the tallest measured.

Temperature and relative humidity were recorded in all plots at 30-minute intervals from 2013-2018 using a HOBO datalogger (Hobo model U23, Onset Corp.,Bourne, MA) positioned inside a solar radiation shield at 1.2 m above the ground and located 5 m outside each plot in a location with similar light availability and species composition. Soil moisture readings were taken at 16 locations within each plot in the spring (early May) of each sample year using a Cambpell Hydrosense, Model CS659 with 12cm rods. Herbaceous understory surveys were conducted in April of each year. *(do we need to include any of these things if we don't report on microclimate/ soil moisture/ herbaceous understory?)*

A second full demographic resurvey was conducted on all 54 plots in 2019 and a partial resurvey (burned plots only) was conducted in 2020 following the Kincade fire. *(elaborate on those survey methods here?)*

We examined post-fire outcomes in all 28 (30 with oak hybrids- leaving them out) woody species present (supplemental table 1), with the exception of poison oak (*Toxicodendron diversilobum*) which was abundant but excluded, in order to quantify mortality, top-kill (with resprouting), and crown survival in relation to pre-fire size (DBH), fire severity, and species. More focused analyses were performed on the 9 most abundant species present in the plot network.

***Analysis:***

Calculated fire severity using the 'Tubbs.MTBS.RDNBR.30'

Chose four fire severity breaks based on RBR values determined by Parks et al. 2014, opted to not use intermediate split at 304: Unburned, Low <170, Medium 170-700, High: >700.

Calculated logDBH for size

Converted sapling diameters to adjusted values based on dbh~sabd regression

Plotted response variables as a function of size, with isoclines as a function fire severity. Increasing lines indicate survival is higher for larger trees, but overall lower at higher fire severity.

We ran a series of Best-fit logistic models for post-fire status (dead, topkill, live-crown) included size, fire severity, species identification, and ‘sizeXseverity’ or ‘sizeXspecies’ interactions.

Delayed mortality- (did we actually do this in tALL?- is there anything to report?)

How many more died in 2019. Alive in 2013 and 2018 but dead in 2019…or even 2020?

Loss of biomass( started this using dyplr- last few lines of examine.data- but never converted to an object for further manipulation)

1. What was the loss of BA (DBH/BD) per species from 13-18?
   1. Added loss of 99###’s – they were dead in 18 but not present in 13 so didn't show up in tag matching. Created dummies in 2013 for these.
      * *Are there any new SAs in 2018 with a tag number that were DN and then not present in 2019 ? if so they should have been 999’s and need to be treated the same as subset above*
   2. Used 2018 sizes for loss of BA. Use 2013 sizes to fill in missing ones in 2018 OR formula to estimate growth from 2013-2018 and back per species/ size class

Built individual fate model to see the fate of every tree- track an individual from date tagged to date of interest. Trees that died in 2018 or 2019 weren’t resurveyed and would be left out (for example tracking an indiv from 2013 out to 2019 or 2020 but the individual died in 2018.)

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**Growth Analysis (notes)**

Loss of Basal Area per species?

Overall BA of species per plot in 2013 and 2018 -looking at change post fire

For TR – use DBH / BA in 2013 compare to DBH of dead and living trees in 2018

- growth until night before fire

For SAs- use BD in 2013 and BD of OG in 2018 on all preexisting tags

-excluding new tags will show growth

-including new tags will show growth + recruitment to SA status

Can calculate change in BD from 2018 to 2019 bc BD measurements are of now dead OG -( i think) but height is of Bsprout (in 2020 BD is of Bsprout)

Can calculate loss of BD in SA’s from fire by comparing change from 2018 (BD night before fire- bc BD was taken for OG dead on 0/1) and 2019 BD which is now of Bsprout

**General notes for consideration:**

-TS’s in 2013 are converted to bsprouts..but how are they dealt with in 2018+..should they be treated as SA’s or left out of analysis when selecting type TR or SA? How many are there?

-In 2013, make sure we are NOT adding 1 to “stems under 10cm” A one in that column is it because there was only one main stem. In 2018 and beyond it was a 0 unless there was 1 additional stem present.

-Did we decide to leave stems under 10cm out as to not overinflate BD estimates by multiplying main stem by number of stems under ten cm? Confirm

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**Results:**

Of the 54 research plots, 7 burned at high severity, 40 burned at moderate to low (18 moderate, 22 low) and 7 were unburned. Of the 28 woody species occurring in the plot network (supplemental table 1), 14 are tree species, including 7 species of oaks, and 14 are shrub species. Out of these, 9 species were considered abundant within the plot network and included in analyses.

All individual stems were assigned one of the four following outcomes post fire: Dead canopy with no resprouts (DN), dead canopy with resprouts (DR), live canopy with no resprouts (LN), or live canopy with resprouts (LR).

[For only 6242 of 6946 indvs? line 147 examine data- is the difference the 999’s? or is this the number of TS’s- NO!! it's the 704 added in 2019]

~~Of the 6946 (remove TS’s for this to be accurate 219 in 2018 and 264 in 2013 169 on 2019 and 25 in 2020) tagged individuals tracked from pre fire in 2013 to post fire status in 2018 43.5% of all individuals died. The mortality rate among trees was 36.8% and among saplings was 50.0%.~~  ( These numbers are off by 1000 now??? I think 6946 is the total trees in tALL and includes the 704 trees added in 2019 and the 264 TS’s in 2013)

Of the 5978 (removed TS’s to be accurate 219 in 2018 and 264 in 2013) tagged individuals tracked from pre fire in 2013 to post fire status in 2018 41.3% of all individuals died. The mortality rate among trees was 36.8% and among saplings was 45.1%.

When considering only the subset of the 9 most abundant species 36.7% of trees died (DN) and 20% were topkilled with resprouts (DR). 43.3% retained a living canopy and of those 9.9% resprouted (LR) and 33.4% did not resprout (LN). For saplings 49.8 % died (DN) and 28.5% were topkilled with resprouts (DR). 21.7% retained a living canopy and of those 0.4% resprouted (LR) and 21.3% did not resprout (LN). The survival rates per abundant species are listed in Tables A and B (decide whether to report raw numbers for each fate or percentages)

We ran a series of generalized linear mixed models using data from pre and post fire, with response variables for either Alive (Live.18), which included top killed individuals with resprouts, or living canopy (g.Crown.18), which included any individual with a green canopy, regardless of resprouting. Predictor variables included in the model were size (log DBH) fire severity (low, med high), species and year (pre fire vs post fire) { glm(formula = Live.18 ~ ldbh + as.factor(fsLevel) + Species.13, family = "binomial", data = tAlls)}.

Full model

fit5 <- glm(yval~ld10+ld10.2+fsCat+northness+Species.18,data=tAlls,family='binomial')

without northness

fit5x <- glm(yval~ld10+ld10.2+fsCat+Species.18,data=tAlls,family='binomial')

without quadratic

fit5l <- glm(yval~ld10+fsCat+northness+Species.18,data=tAlls,family='binomial')

These models allowed us to predict post fire outcomes as a function of size. Figure X

These are binomial regression analysis for each outcome, plotted on one graph, we can also use a multinomial regression and get nearly identical results (did we decide to use those instead?)

**Discussion:**

Stands dominated by resprouting hardwoods likely to return to pre-fire conditions overtime

Douglas-fir dominated sites- potential for type conversion or invasion as understory species

Quantification of post-fire responses, coupled with knowledge of drought-tolerance, can help project the impacts of future climate change and wildfire on these systems.

-Bark thickness as future direction-

DBH not a causal predictor of survival, really a proxy for bark thickness and height.

Use estimates of bark thickness? DONE- no relationship

Is there a universal relationship/ predictor for bark thickness / species? NO

Can we get tree height from Lisa Bently- NO needs to be extracted…

Zane cooper – ssu masters student estimates at least 40hrs of work

Allometry of bark thickness and size- 5cm of all species

Use DBH but interpret with reference to bark thickness based on common size

Handbook of plant functional Ecology – Julietta Rosell- how to measure bark thickness

-Species composition/ community shifts

DA analysis on community shift- to date no evidence to support community shifts, but this is using tree data within specific size class. What about saplings in high severity- thinking ceacun on grouse hill?

**Literature Cited:**

Halbur M, Kennedy M, Ackerly D, Micheli L, Thorne J. 2013. Creating a Detailed Vegetation Map for Pepperwood Preserve. Moore Foundation Technical Report.

Oldfather MF, Britton MN, Papper PD, Koontz MJ, Halbur MM, Dodge C, Flint AL, Flint LE, Ackerly DD. 2016. Effects of topoclimatic complexity on the composition of woody plant communities. AoB PLANTS 8: plw049; doi: 10.1093/aobpla/plw049

Parks SA, Dillon GK, Miller C. A New Metric for Quantifying Burn Severity: The Relativized Burn Ratio. *Remote Sensing*. 2014; 6(3):1827-1844. <https://doi.org/10.3390/rs6031827>

Studio Team (2020). RStudio: Integrated Development for R. RStudio, PBC, Boston, MA URL <http://www.rstudio.com/>

**Supplemental Tables**

Table 1. (delete hybrids? Include counts of individuals? Those can be pulled from examine.data) Abundant species used for analyses in bold

|  |  |  |
| --- | --- | --- |
| CODE | SPECIES | COMMON NAME |
| ADEFAS | *Adenostoma fasciculatum* | Chamise |
| AESCAL | *Aesculus californica* | Buckeye |
| AMOCAL | *Amorpha californica* | California false indigo |
| **ARBMEN** | ***Arbutus menziesii*** | **Madrone** |
| **ARCMAN** | ***Arctostaphylos manzanita*** | **Manzanita** |
| BACPIL | *Baccharis pilularis* | Coyote bush |
| CEACUN | *Ceanothus cuneatus* | buckbrush |
| CEAPAR | Ceanothus parryi | Parry ceanothus |
| CERBET | *Cerocarpus betuliodes* | Mountain mahogany |
| CORCOR | *Corylus cornuta* | California hazelnut |
| FRACAL | *Frangula californica* | Coffeeberry |
| **HETARB** | ***Heteromeles arbutifolia*** | **Toyon** |
| HOLDIS | *Holodiscus discolor* | Oceanspray |
| NOTDEN | *Notholithocarpus densiflora* | Tanoak |
| PRUCER | *Prunus cerasifera* | Cherry plum |
| **PSEMEN** | ***Pseudotsuga menziesii*** | **Douglas-fir** |
| **QUEAGR** | ***Quercus agrifolia*** | **Coast live oak** |
| QUEBER | *Quercus berberidifolia* | Scrub oak |
| QUEBEGA | *Quercus berberidifolia/garryanna* | Scrub oak/Oregon oak |
| QUEDOGA | *Quercus douglasii/garryanna* | Blue oak/Oregon oak |
| **QUEDOU** | ***Quercus douglasii*** | **Blue oak** |
| **QUEGAR** | ***Quercus garryana*** | **Oregon oak** |
| **QUEKEL** | ***Quercus kelloggii*** | **Black oak** |
| QUELOB | *Quercus lobata* | Valley oak |
| QUEWIS | *Quercus wislizeni* | Interior live oak |
| RHACRO | *Rhamnus crocea* | Redberry buckthorn |
| SAL\_SP | *Salix sp.* | Willow sp. |
| SAMNIG | *Sambucus niger* | Elderberry |
| TORCAL | *Torreya californica* | California nutmeg |
| **UMBCAL** | ***Umbellularia california*** | **California Bay** |

------------Notes to be moved --------

**Woody protocol notes**

COMPILE THESE NOTES INTO A README FILES FOR 2018. 2019. 2020

UNIQUE DATA COLLECTION METHODS

**2013**

If a TS- this is really a stump sprout aka a basal resprout. These TS’s pre fire were converted in PWfunctions.local into trees with a basal resprout. TS’s were left as this type in subsequent years. This may be off bc then are those trees with TS’s treated as trees with resprouts post fire too? No – only post fire resprouts are tracked post fire and indicated with a 0/1 for survival and bsprout

**2018**

0/1 is a topkilled individual with basal resprouts. For SA’s the OG BD was recorded to collect growth (2013-2018) and to determine basal area per species, the night before the fire. When possible, new SA’s also had the OG BD recorded. Can’t include these in a BA of living SA’s this year. Is there any reason to calculate BA of living SA’s in 2018?

**2019**

SA’s that were 0/1 in 2018 were now recorded as 1/0 and the BD of the bsprout was collected in order to get the BA per species of living individuals (don't have BA of living/ new SA’s in 18)

The height of a bsprout on an SA is listed under BSPT height not SA height for all 0/1

all 1/0 are listed under SA height. Need to move.

Moving data from count >50 Bsprout column into SA stem # for all 0/1 SA’s (did this all happen in qc?)

In 2019 we only took DBH on living trees bc dead trees don’t get bigger. In 2020 we didn’t take any- basically only need DBH in 2018 to compare to 2013.

SO a lot of sa’s might be off… so 1/0 is really a now taller/ living sprout of dead OG, that was 0/1 in 2018…and the BD is of the bsprout. unless it was alive in 18 and 19- then BD is of the OG ???

**2020**

Back to 0/1 for topkilled individuals post Kincade

Started taking BD of the thickest Bsprout at most plots - started on 1345 survey date

**General data structure notes** – these are somewhere else…check that before deleting

* in 2019, the height of a Bsprout on an SA is listed under BSPT height not SA height for all 0-1 all 1-0 are listed under sa height. Need to move in R
* In 2019 moving data from count >50 Bsprout column into SA stem # for all 0-1 SA’s (did this all happen in qc?)
* In 2019 we only took DBH on living trees bc dead trees don’t get bigger. In 2020 we didn’t take any- basically only need DBH in 2018 to compare to 2013.
* a lot of sa’s might be off… so 1/0 is really a now taller/ living sprout of dead OG, that was 0/1 in 2018…and the BD is of the Bsprout. unless it was alive in 18 and 19- then BD is of the OG ???
* basically can calculate change in BD from 2018 to 2019 bc BD measurements are of now dead OG -( i think) but height is of Bsprout ( in 2020 BD is of Bsprout)
* okay - yes its true for 0/1’s the bd is of the og and the height of the resprout is under 50 and recorded in bsprout height not SA height. there is no stem under count. maybe there is- if there is a count in over 50 then we can assume its the stems under- but if there is not can we assume that its zero?
* SOD on bay is a column on the data sheets in 2019/2020, but in notes section in 2018
* In 2019- bd of og in notes, or bd of bsprout- which one do we want?