Fire Management for Climate Change Refugia

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Figure 2. Potential climate refugia indicator species which reach their southern range extent in the central Sierra Nevada.

Introduction

Early climate change predictions were for catastrophic species extinctions. As scientists investigated species response to climate change further, a more nuanced perspective emerged indicating species may be able to persist in climate refugia. This phenomenon is especially apparent in complex terrain such as the mixed conifer zone of the Sierra Nevada which has cold-refugia.

Cold-refugia (refugia) form at the intersection of relatively mesic areas with cold-air pools (Figure 1) and/or north-facing slopes.

Figure 1. Cold-air pool landscape position & physics.

Here, many species exist at their southern range extent and do not exist outside of refugia at this latitude (Figure 2). Climate change's predicted increased warmth and amplified disturbances may cause local extirpation of some refugia species. Concomitantly, these regions may become refugia for other species which are currently common in the region but may become rare and/or restricted to refugia with climate changes. Refugia not only have distinct communities, but they may also exhibit distinct ecological processes from surrounding areas, such as fire frequency or severity.

Goals

(1) Examine published data for insights and limitations of refugia fire ecology. Specifically, *do refugia have similar fire occurence and severity to the adjacent forests?*

(2) Infer the vulnerability of refugia to fire.

Materials

Within Yosemite National Park's mixed conifer forests (Figure 3):

- Cold-air pool (CAP) model as proxy for climate change refugia (Figure 4; Lundquist, 2008)
- Fire history polygons from 1930 to 2012 (Figure 5)
- Fire severity delimited with Relative differenced Normalized Burn Ratio (RdNBR) from 1984 to 2012 (Figure 6; Miller 2012)

Methods

Data was randomly subsampled from a 100 m point grid to reduce spatial autocorrelation and equal samples sizes from all levels of CAPs (absent, marginal, present) were randomly sampled for both fire occurrence and severity

We constructed statistical models to test if cold-air pools are related to fire occurrence or severity:

$$\gamma \sim \text{Cold air pool}$$

Where γ is the response variable, either fire occurrence (absent: 0, present: 1) or fire severity (ordered classes where very low: 1, low: 2, moderate: 3, high: 4). Cold-air pool categories include absent, marginal, and present.

We used GLMs with binomial distribution for fire occurrence and Gaussian distribution for fire severity the ordered fire severity classes.

Figure 3. Study area

Boundaries
- Study Area
- Yosemite National Park

Kilometers
0 25 50

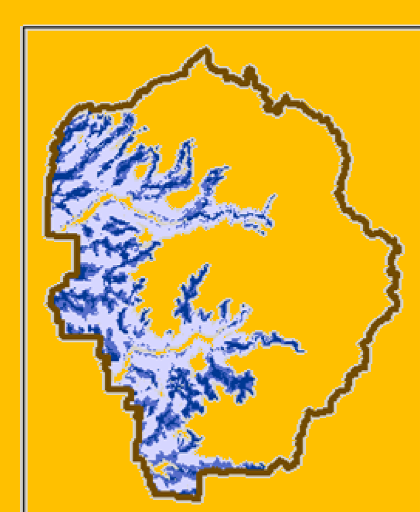

Figure 4. Cold-air pool model (Lunquist, 2008)

Cold-air pools
- Absent
- Marginal
- Present

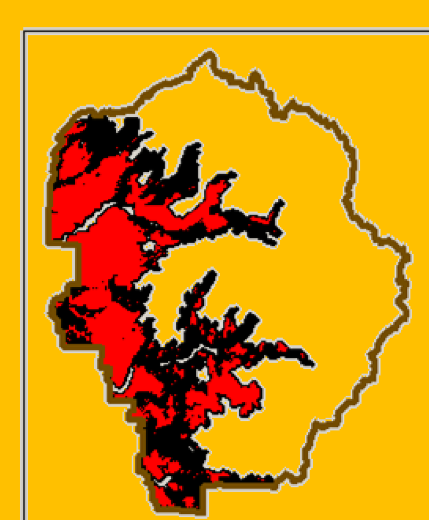

Figure 5. Fire history polygons from 1930 to 2012

Fire history
- Area with fire
- Study Area

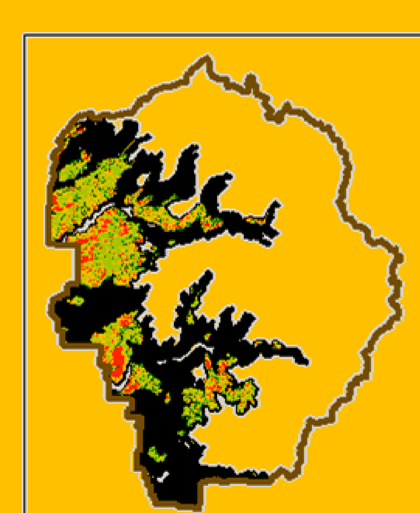

Figure 6. Fire severity delimited with Relative differenced Normalized Burn Ratio (RdNBR) from 1984 to 2012 (Miller 2012)

Fire Severity
- Very low
- Low
- Moderate
- High
- Study Area

Results

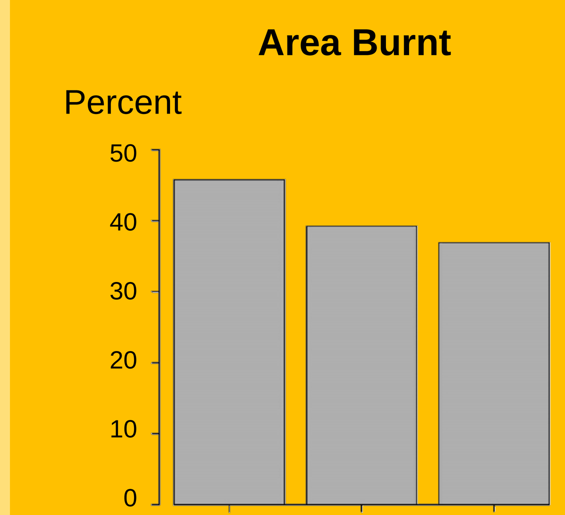

Figure 7. Percent of area burnt grouped by cold-air pool (CAP) level. CAPs were less likely than the surrounding area to burn from 1930 to 2012 (Est: -0.4 +/-0.02, P < 2e-16). Even marginal CAPs were less likely to burn than areas without CAPs (Est: -0.29 +/- 0.02, P < 2e-16)

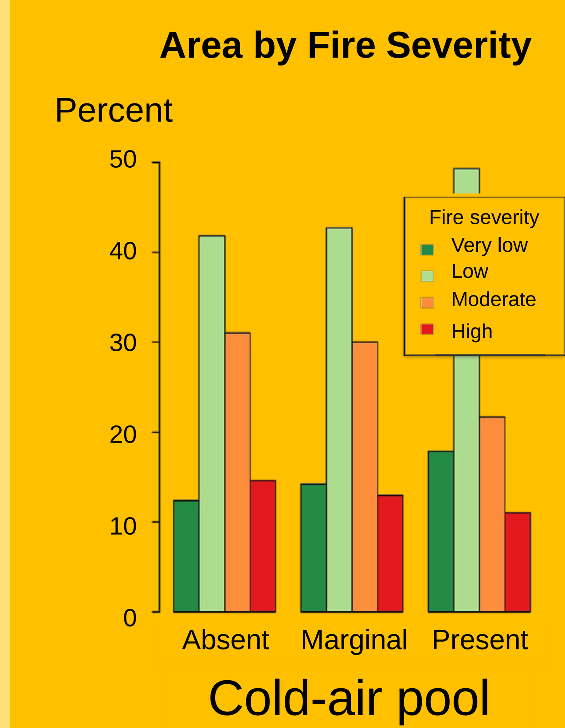

Figure 8. Percent of area with unique fire severities grouped by and cold-air pool (CAP) level in burnt areas. If CAPs burned, they were more likely to burn at a lower fire severity than the surrounding area burned from 1984 to 2012 (Est: -0.06 +/- 0.01, P = 2.97e-05). Even marginal CAPs had less severe fire than areas without CAPs (Est: -0.06 +/- 0.01, P = 2.97e-05)

Discussion

Fire extent and severity may be moderated by direct and indirect effects of CAP and land management (Figure 9). The factors critical to fire behavior (weather, fuel, and topography) vary spatially and temporally.

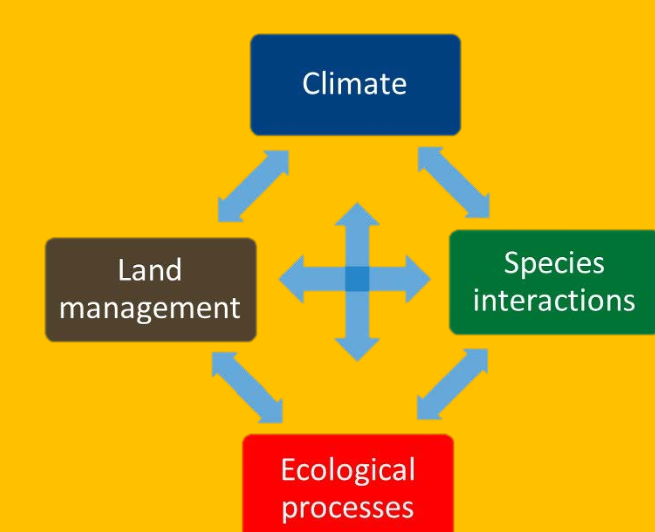

Figure 9. Refugia ecology is complex and affected by climate, land management, species interactions, and ecological processes, and their interactions. CAPs may have direct effects on fire behavior (temperature, wind, and fuel moisture) as well as indirect effects mediated through vegetation (amount of fuel, forest structure, relative humidity).

Refugia are defined by their distinct climates which may directly affect some fire behavior.

•CAPs may be cooler in the evening and morning but reach similar maximum daytime temperatures as surrounding areas.

•CAPs are more productive that surrounding areas.

•CAPs' fuel has more moisture than the surrounding area because it is moderated by temperature and relative humidity. *Fuel moisture differences may have less fire behavior effects during late fall and/or droughts.*

The interaction between CAP and fire may be moderated by season and weather's impact on fire behavior (Figure 10). Therefore, fire management and climate change may affect CAP and fire interaction.

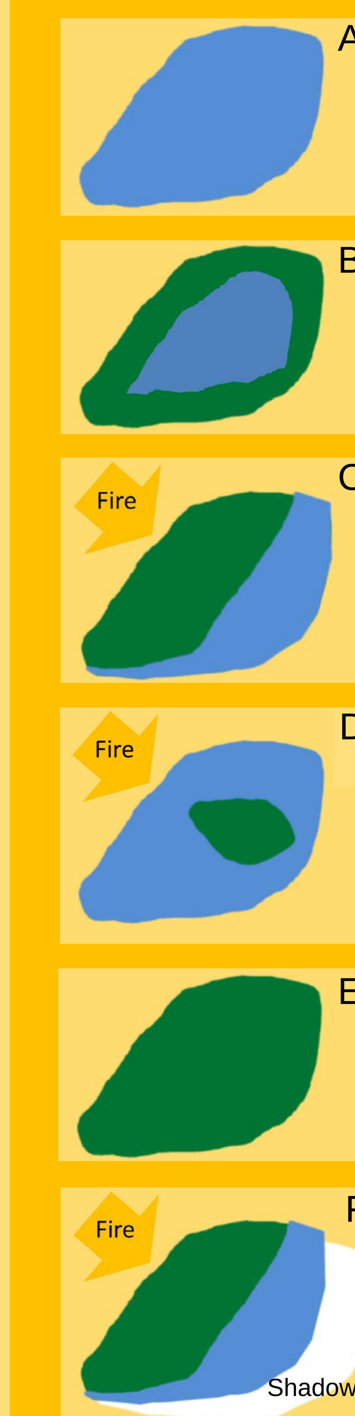

Figure 10. The interaction of fire and CAPs may be dependent upon fire behavior including the fire's direction, magnitude, and intensity. The yellow background indicates where fire occurred and the golden arrows indicate the fire's direction of movement. **(A)** Fires which move slowly (low magnitude) and release little energy (low intensity) may respond quickly to a refugium's microenvironment and not penetrate the CAP, whereas **(B)** fires with higher magnitude and intensity may respond slowly to a CAP (burn a buffer around the perimeter), **(C)** and/or a larger region near the flame front, **(D)** a spot fire ignites within the CAP and grows especially during dry windy conditions, or **(E)** even burn the entire CAP. **(F)** There also may be a CAP fire shadow where a reduction in fire extent or severity occurs because of its proximity to a CAP and the CAPs reduction in fire presence or severity.

Fire
Cold-air pool
Intersection of fire & cold-air pool

Conclusions

- CAPs have less frequent and lower severity fires.
- Prescribed burns are one of the best tools to prepare healthy forests that harbor biodiversity as the climate changes.
- However, refugia may need special management techniques because of their historical ecology.
  - Short term:
    - Fire may be a direct threat to refugia inhabitants.
  - Long term:
    - Fire may be an indirect benefit to refugia inhabitants by preventing severe wildfires.
    - Lack of fire may exacerbate climate change's increasing disturbance threats to biodiversity, including increased fire frequency & severity.

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