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Title: Smokey the Beaver: beaver-dammed riparian corridors stay green during wildfire throughout the western USA

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Abstract

Beaver dams are gaining popularity as a low-tech, low-cost strategy to build climate resiliency at the landscape scale. They slow and store water that can be accessed by riparian vegetation during dry periods, effectively protecting riparian ecosystems from droughts. Whether or not this protection extends to wildfire has been discussed anecdotally but has not been examined in a scientific context. We used remotely sensed Normalized Difference Vegetation Index (NDVI) data to compare riparian vegetation greenness in areas with and without beaver damming during wildfire. We include data from five large wildfires of varying burn severity and dominant landcover settings in the western USA in our analysis. We found that beaver-dammed riparian corridors are relatively unaffected by wildfire when compared to similar riparian corridors without beaver damming. On average, the decrease in NDVI during fire in areas without beaver is 3.05 times as large as it is in areas with beaver. However, plant greenness rebounded in the year after wildfire regardless of beaver activity. Thus, we conclude that while beaver activity does not necessarily play a role in riparian vegetation post-fire resilience, it does play a significant role in riparian vegetation fire resistance and refugia creation.

Keywords: beaver; dam; wildfire; remote sensing; NDVI; riparian; drought; burn; vegetation

1 Introduction

Beavers are native to North America (*Castor canadensis*) and to Eurasia (*Castor fiber*) (Naiman et al. 1988, Wróbel 2020). They occupy a variety of landscapes, including mountain streams, lowland valleys, coastal estuaries, deserts, arctic tundra, and temperate forests. (Naiman et al. 1988, Leidholt-Bruner et al. 1992, Pilliod et al. 2017, Tape et al. 2018). Beavers are well known ecosystems engineers – they build channel-spanning dams from wood, stone, and mud which ultimately create the broad ponds and wetlands that beavers thrive in (Hammerson 1994). Beavers also excavate mud from the pond bottom and dig channels (also referred to as canals) radiating from the pond out into the surrounding landscape which fill with water and increase their area of influence (Gurnell 1998). The combination of building flow obstructions (dams), accumulating water (ponds), and spreading that water out in the landscape (channels) gives beavers the unique potential to modulate environmental

extremes such as flood and drought (Hood and Bayley 2008, Pilliod et al. 2017, Fairfax and Small 2018, Westbrook et al. 2020). When it comes to water, beavers slow it, spread it, store it.

Due to the fact that beaver channels and dams spread water out in the landscape and store it broadly in adjacent soils (Figure 1, top), the vegetation near beaver ponds doesn't experience as much reduced water availability during drought (Macfarlane et al. 2016, Pilliod et al. 2017, Fairfax and Small 2018) (Figure 1, middle). Drought-stricken vegetation burns more easily than lush, green vegetation (Liu et al. 2010), so it follows that the vegetation around beaver ponds would be more difficult to burn than vegetation around undammed creeks (Figure 1, bottom). Although this concept has been observed, discussed, and documented in photographs (Figure 2), the potential difference in vegetation health during wildfire in areas with and without beaver has not yet been quantified (Foster et al. 2020). In this study we use satellite-derived Normalized Difference Vegetation Index (NDVI) data from the year before, year of, and year after a major wildfire to examine the vegetation changes of riparian corridors with and without beaver. We include data from five large wildfires located in five different western U.S. states: Colorado, California, Oregon, Idaho, and Wyoming to quantify the extent to which, if any, vegetation in beaver-dammed riparian areas can stay green during wildfire.

2 Methods

2.1 Site Selections and Descriptions

We examined fires with differing burn severities and landcover to help determine whether the response of riparian areas with beaver-dam complexes to wildfire could be generalized beyond specific case studies. Table 1 provides a brief summary of the fires included in this study and the data used for each. The fires included in this study occurred in a variety of landcover types as determined by the 2016 National Landcover Database (Homer et al. 2020). Three of the fires studied occurred in shrubland dominant landscapes, and two occurred in forest dominant landscapes. The burn severity of the fires varied as well, with three fires that were majority unburned to low burn severity, and two fires that were majority moderate to high burn severity. Burn severity and fire perimeters were collected from the Monitoring Trends in Burn Severity Database and the GeoMAC Wildland Fire Support Database. (Eidenshink et al. 2007, USGS 2019). Fires occurred in areas with varying drought status in the years before, of, and after the fire. Drought severity was determined using the Palmer

Drought Severity Index from the NOAA Gridded Climate Divisional Dataset (Palmer 1965, Vose et al. 2014). Full detailed fire information can be found in Appendix S1: Table S1.

Each fire contained creeks with heterogenous patches of beaver activity. We determined where beavers were influencing riparian corridors in our study by locating and recording the position of beaver dams, ponds, and beaver-dug channels using satellite images acquired through Google Earth. Previous studies have successfully used aerial imagery and Google Earth to locate and identify beaver dams (Macfarlane et al. 2015, Puttock et al. 2015, Fairfax and Small 2018).

2.2 *General Process for Evaluating Impact of Beavers on Riparian Wildfire Resistance*

Our procedure to determine whether, and to what extent, beaver activity protects riparian vegetation during wildfire is outlined below and again graphically in Appendix S2: Fig. S1.

1. collect geospatial (e.g. coordinates of dams, pond area polygon, dam length vectors) for each beaver dam within the fire perimeters
2. extract remotely sensed NDVI along each creek that had patches of beaver activity on approximate date (month/day) of wildfire in year before, during, and after wildfire.
3. difference between pre-fire NDVI and fire NDVI is calculated at each site and graphically compared to locations of beaver dams
4. divide creeks into sections broadly impacted by beaver activity and sections that do not have beaver activity, unscaled NDVI Differences in beaver and non-beaver areas are compared at the creek and wildfire scales
5. use the maximum NDVI Difference on each creek to scale the changes in NDVI so sites can be compared while accounting for variation in burn severity, landcover, and climate
6. compare scaled NDVI changes in areas with and without beaver across all study sites

Following these steps allows us to move from site-specific case studies of individual creeks within larger wildfire-impacted landscapes, to generalized vegetation response to wildfire in riparian corridors with and without beaver activity.

2.3 *NDVI Collection and Calculations*

Previous studies indicate that Normalized Difference Vegetation Index (NDVI) can be used as a proxy for overall riparian vegetation health, and that it can be estimated from remotely sensed data (Macfarlane et al. 2016). High NDVI (values close to 1) generally indicated lush, greener vegetation while very low NDVI (values close to 0 or negative) generally indicate unhealthy, senesced, or dying vegetation. In more densely vegetated areas – including riparian zones – an NDVI below 0.3 is considered to be indicative of low plant health and productivity (Nagler et al. 2001, Donnelly et al. 2016, Huntington et al. 2016, Silverman et al. 2019). In this study, we use the 0.3 NDVI threshold, Google Earth aerial imagery, and landcover data to determine where riparian vegetation is present before the fires.

Apart from the 2000 Manter Fire in California, we calculated NDVI from Landsat 8 imagery. Landsat 8 imagery is available from April 2013 through the present, has 30m x 30m pixel resolution on its red (R) and near-infrared (NIR) bands, and a 16-day recurrence interval. For the Manter Fire, we used Landsat 7 imagery. Landsat 7 imagery is available from April 1999 through present and has the same pixel resolution in R and NIR and recurrence interval as Landsat 8. The Landsat imagery dates used for each fire are summarized in Appendix S1: Table S1 and were chosen based on timing and cloud-free status. The NDVI is calculated from Landsat acquired reflectivity data according to Equation 1 (Tucker 1979):

$$\text{NDVI} = (\text{NIR} - \text{Red}) / (\text{NIR} + \text{Red}) \quad \text{Eq. 1}$$

where NIR is the near-infrared band reflectivity and Red is the red band reflectivity. All images came with a quality assessment statement regarding whether the integrity of data had been affected by instrument artifacts or atmospheric conditions and were sourced directly from the USGS Earth Resources Observation and Science (EROS) Center Science Processing Architecture (ESPA) (USGS 2014). We extracted NDVI values at each pixel immediately adjacent to the creek ($\leq 30\text{m}$ distance from creek edge) for all creeks in the study in the year before, the year of, and the year after the fire on the approximate date (month/day) of the wildfire. Higher values indicate greener vegetation. This narrow area is the most heavily and consistently impacted by beaver activity and least likely to be influenced by short term changes in beaver occupancy. However, beaver activity often supports

riparian vegetation well beyond the 30m radius (Gurnell 1998). A larger dataset with on-ground riparian zone surveys before, during, and after wildfire would be needed to robustly quantify the total area of riparian zone influenced by beaver activity. In the absence of that data, our results should be interpreted as a conservative assessment of the refugia that beavers can support during wildfires.

Vegetation response to wildfire was calculated by subtracting the NDVI during the wildfire from the NDVI at the same time of year in the year prior to the wildfire (Equation 2).

$$\text{NDVI Difference} = \text{NDVI}_{\text{pre-fire}} - \text{NDVI}_{\text{fire}} \quad \text{Eq. 2}$$

With this formulation smaller values for NDVI Difference indicate greater resistance to wildfire, i.e. the plants stayed greener and burned less. This type of formulation has been utilized in prior work to evaluate change in vegetation condition as a response to environmental stressors (Nagler et al. 2001, Macfarlane et al. 2016, Fairfax and Small 2018, Silverman et al. 2019).

We considered the 95th percentile NDVI Difference value to be the maximum NDVI Difference occurring on each creek. These values are the scaling factors which allow for comparisons between creeks and wildfires while accounting for burn heterogeneity within fire perimeters and variations in vegetation cover, climate, and burn intensity between fires using the formulation shown in Equation 3.

$$\text{Scaled NDVI Difference} = (\text{NDVI Difference}) / (\text{Max NDVI Difference on Creek}) \quad \text{Eq. 3}$$

The lower the Scaled NDVI Difference value, the more fire resistant the riparian vegetation in that section of creek is. We used the Scaled NDVI Difference calculated for each pixel along each creek to generate two populations of data – one from sections of creek that had beaver activity, one from sections of creek that did not have beaver activity. To be considered part of a section with beaver damming, it had to be within 30m longitudinally of a beaver pond, dam, or channel. This is a conservative estimate of the spatial scale of hydrologic connectivity around beaver ponds (Wegener et al. 2017). Each population of data contains data from multiple creeks, fires, landcover types, burn intensities, climate histories, and years – thus the results of comparing the populations should be considered more generalizable than only comparing within a given creek or wildfire perimeter. In addition to comparing mean values and general distributions of data, we perform statistical

comparisons to quantify the significance of our results. We use the Kolmogorov-Smirnov (KS) Test (Massey 1951) and the Welch Two-Sample t-test (Welch 1947). The KS test evaluates whether two populations of data come from a single distribution of data or two distinct distributions, and the t-test evaluates the likelihood that both samples have identical mean values. For all tests, $p < 0.05$ was our threshold for significance. The population size of pixels used for statistical tests of NDVI Difference at the creek-scale, wildfire scale, and combined data scale are in Appendix S4: Tables S1 and S2.

3 Results

3.1 NDVI Along Creek Profiles

We collected the NDVI along each creek in the study in the year before, during, and after the fire on the approximate date (month/day) of the wildfire. Our data from a creek in the Manter Fire in California is shown in Figure 3 and is representative of the results we saw across all creeks. In Figure 3 (top), the locations of beaver dams are marked along the x-axis with black squares. Higher NDVI values indicate greener vegetation. The full set of plots showing NDVI before, during, and after fire as a function of distance along creek can be found in Appendix S3: Fig S1.

From the pre/during NDVI profiles along each creek, we calculated the NDVI Difference (Eq. 2) and again plotted it as a function of distance along creek with the position of beaver dams marked by black boxes. Figure 3 (bottom) is the NDVI Difference plot derived from the data in Figure 3 (top). The full set of plots showing NDVI Difference as a function of distance along creek can be found in Appendix S4: Fig. S1. A lower NDVI Difference value indicates greater resistance to wildfire, i.e. plants in that area are burning less if at all. These NDVI Difference profiles were split into sections with and without beaver damming according to the criteria listed in Section 2.3. From the 12 creeks in the study, we ultimately split them into a total of 61 sections: 32 sections with beaver damming and 29 sections without beaver damming. We calculated the maximum NDVI Difference value for each creek which is used as the scaling factor to allow comparisons between creeks. These are summarized in Appendix S4: Table S1.

3.2 Unscaled and Scaled NDVI Differences from All Sites

We determined that beaver impacted areas had significantly higher NDVI on the individual creek scale (unscaled NDVI Difference), within a wildfire (unscaled NDVI Difference), and in our

combined data (scaled NDVI Difference). The full set of box and whisker plots detailing these results are in Figure 4. The average Scaled NDVI Difference in sections of creek without beaver activity was 3.05 times larger than in areas with beaver activity (0.58 without beavers, 0.19 with beavers). These differences were significant using both statistical tests, with p-values < 0.001 . We compared pre-fire to post-fire NDVI in areas with beaver vs areas without beaver to probe whether beaver damming may also play a role in riparian corridor recovery in the year after a fire occurs. The full details of these comparisons can be found in Appendix S4: Table S3. We found very little difference (average NDVI Difference = 0.07) between pre-fire and post-fire NDVI, and that beaver activity was not correlated with whether the pre-fire or post-fire year was greener (higher NDVI). Thus, the ability for a burned riparian area to rebound after fire is not dependent on beaver activity.

4 Discussion

Our results indicate that beaver damming plays a significant role in protecting riparian vegetation during wildfires, and that this is a consistently observable phenomenon across landscapes. The riparian vegetation near beaver dams maintained NDVI values during wildfire that were similar to their pre-fire values. Meanwhile the riparian NDVI was significantly reduced from its pre-fire value when not near a beaver dam. The Scaled NDVI Differences in sections of creek that did not have beaver were on average more than three times as affected by fire as areas that had beaver. This is consistent with our conceptual model for fire resistance (Figure 1) and with observed fire burn patterns around beaver ponds (Figure 2). When a fire does ignite, our data suggests that the beaver-dammed riparian areas have enough stored water which kept plants hydrated enough to make it energetically unfavorable to burn. It's similar to trying to start a fire with a pile of wet leaves versus with dry kindling.

These ribbons of fire-resistant riparian corridor may be particularly important for species that are unable to physically escape wildfire. They can provide temporary habitat for fish, amphibians, reptiles, small mammals, wild and domestic ungulates, and birds that are unable to outrun/outfly the spread of flames. While we found that beaver activity does play a significant role in maintaining vegetation greenness during wildfires, it does not appear to play a significant role in the ability for a riparian corridor to rebound in the year following fire. Riparian vegetation NDVI rebounded in the

year following the fire regardless of proximity to beaver activity. Thus, we would describe beaver activity as creating refugia during wildfire, but not necessarily changing the long-term landscape outcomes.

The western USA used to have much more wetland area than it does today, so it is possible that historically beavers were less necessary for creating fire resistant landscape patches (Mitsch and Gosselink 1993). But as it stands today, wetland habitat is very limited and beavers can create and maintain wetland habitat that persists through flood, drought, and as we have shown in this study – fire. This has immediate relevance to scientists and practitioners across the North America and Eurasia – particularly in places with increasing wildfire risk and existing or planned beaver populations. Perhaps instead of relying solely on human engineering and management to create and maintain fire-resistant landscape patches, we could benefit from beaver’s ecosystem engineering to achieve the same goals at a lower cost.

5 Acknowledgments

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Supporting Information

Additional supporting information may be found online at: [link to be added in production].

Data Availability

The data that support the findings of this study are openly available in Pangaea at <https://doi.pangaea.de/10.1594/PANGAEA.900944>

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7 Tables

Table 1: Brief Summary of Fire Information Included in Study

State	Year	Name	Area Within Perimeter (acres)	# of Beaver Dams	Burn Severity (%Unburned-Low / %Moderate / %High)	Dominant Landcover
California	2000	Manter	79,182	57	46 / 32 / 22	Shrubland
Colorado	2016	Beaver Creek	38,380	364	38 / 23 / 39	Forest
Idaho	2018	Sharps	64,811	62	57 / 43 / <1	Shrubland
Oregon	2014	Buzzard Complex	395,348	48	87 / 13 / <1	Shrubland
Wyoming	2018	Badger Creek	21,322	190	54 / 36 / 10	Forest

8 Figure Legends

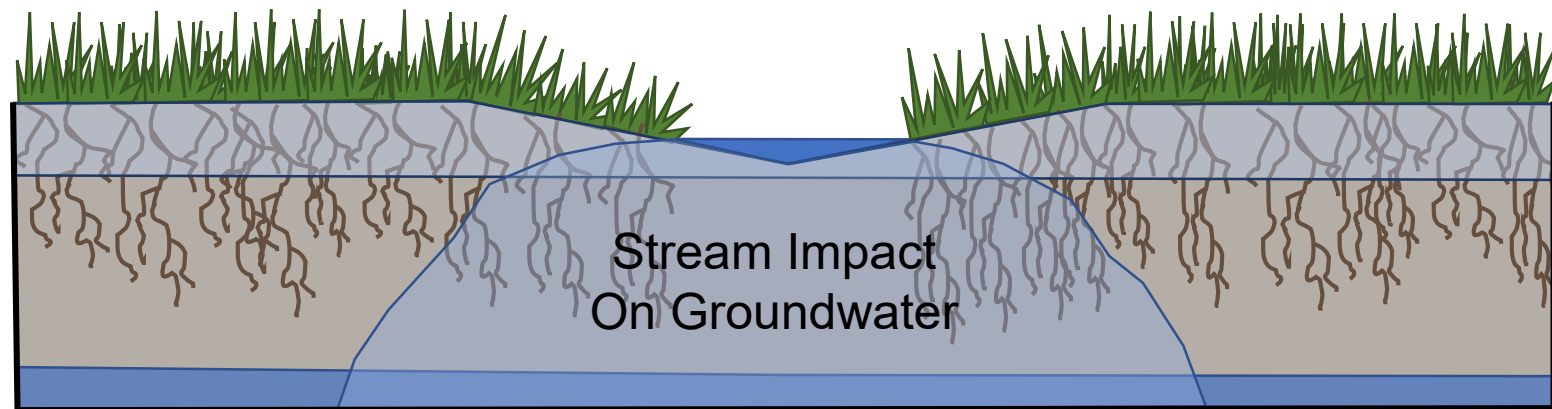
Figure 1: Conceptual model of vegetation response to normal conditions (top), drought (middle), and fire (bottom) in creeks with (right) and without (left) beaver.

Figure 2: Photographs of vegetation response to wildfire around beaver ponds. In both examples, vegetation near beaver ponds stayed green while other nearby riparian vegetation burned. A) adjacent creeks with and without beaver damming during the Manter Fire in California. Photograph from the Burned Area Emergency Response (BAER) team. B) a creek with a beaver pond on it in Oregon prior to the Buzzard Complex Fire. C) the same location as B, except image is from immediately after the wildfire (Google 2014).

Figure 3: Top) NDVI before (green), during (brown), and after (blue) wildfire along a creek in California during the 2000 Manter Fire. Higher NDVI values indicate greener plants. Bottom) NDVI Difference (Pre-Fire NDVI minus Fire NDVI) along the same creek. The locations of beaver dams are marked with black squares along the x-axis.

Figure 4: Box plots of NDVI Difference (Pre-Fire NDVI minus Fire NDVI) in beaver vs non-beaver areas at three scales: a) individual creek scale, b) wildfire scale, and c) all data combined. Lower absolute NDVI Difference and Scaled NDVI Difference values indicate greater vegetation resistance to wildfire, i.e. plants burned less. The difference in means and distributions for every box plot shown was statistically significant ($p < 0.05$). NDVI Differences are unscaled in a) and b). NDVI Differences are scaled by the Max NDVI Difference in c).

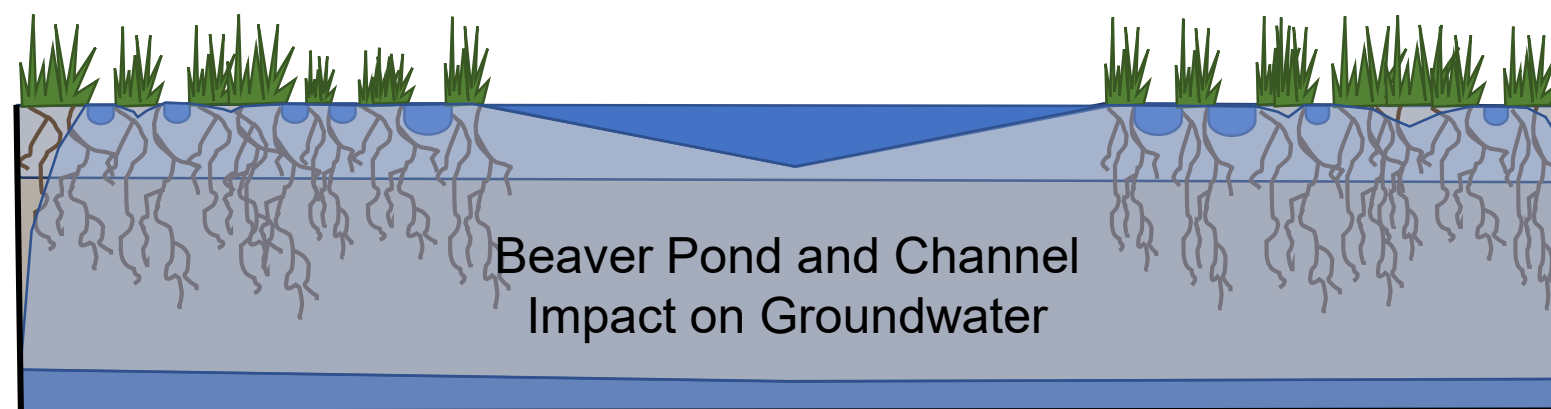
Stream without Beavers



Infiltrating Precipitation

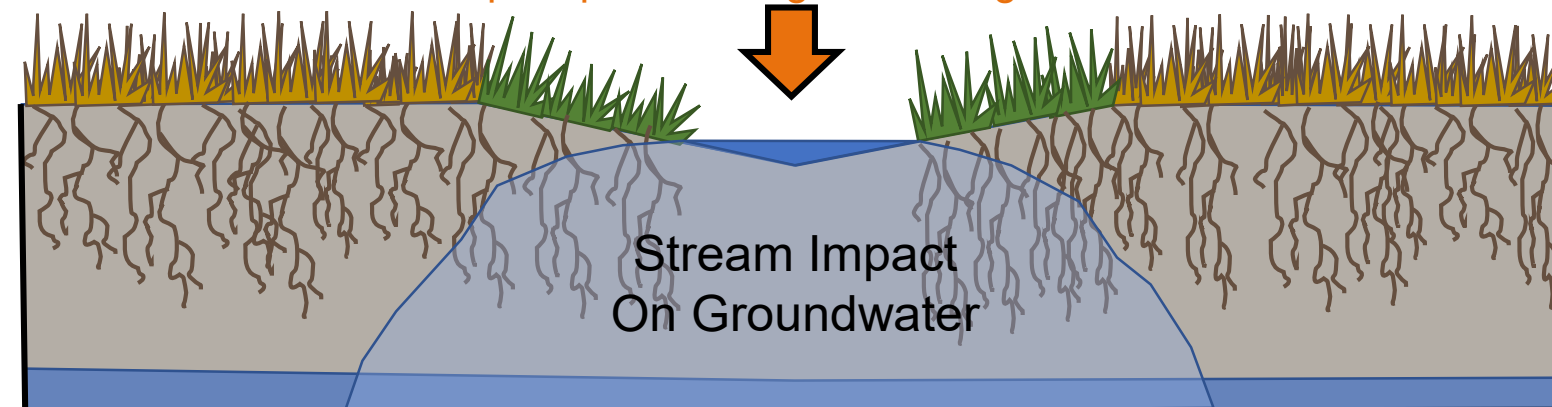
Deep Water Table

Stream with Beavers



Drought Conditions

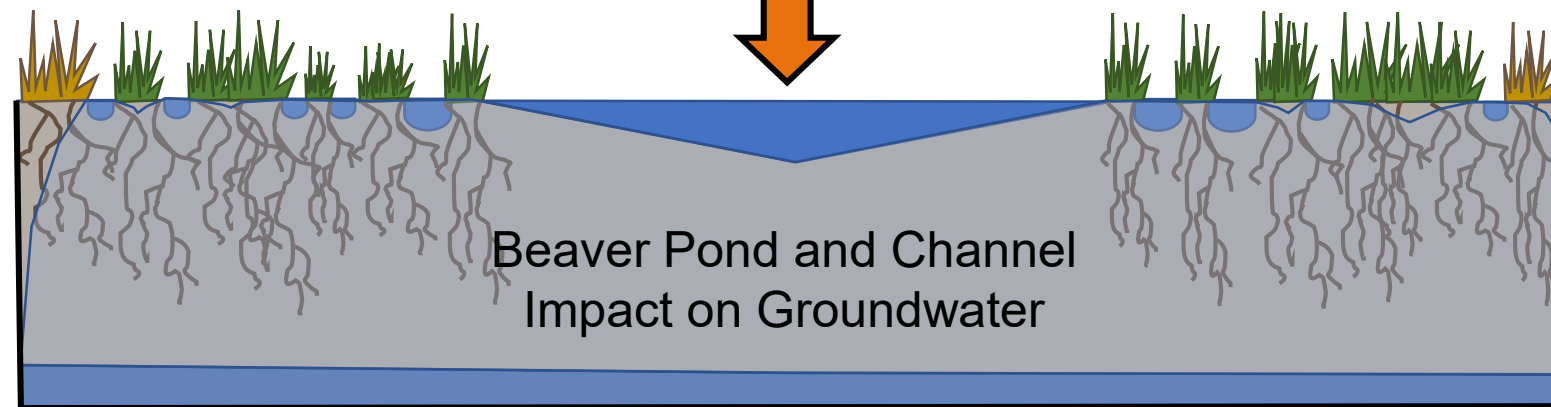
less precipitation, veg relies on groundwater



Deep Water Table

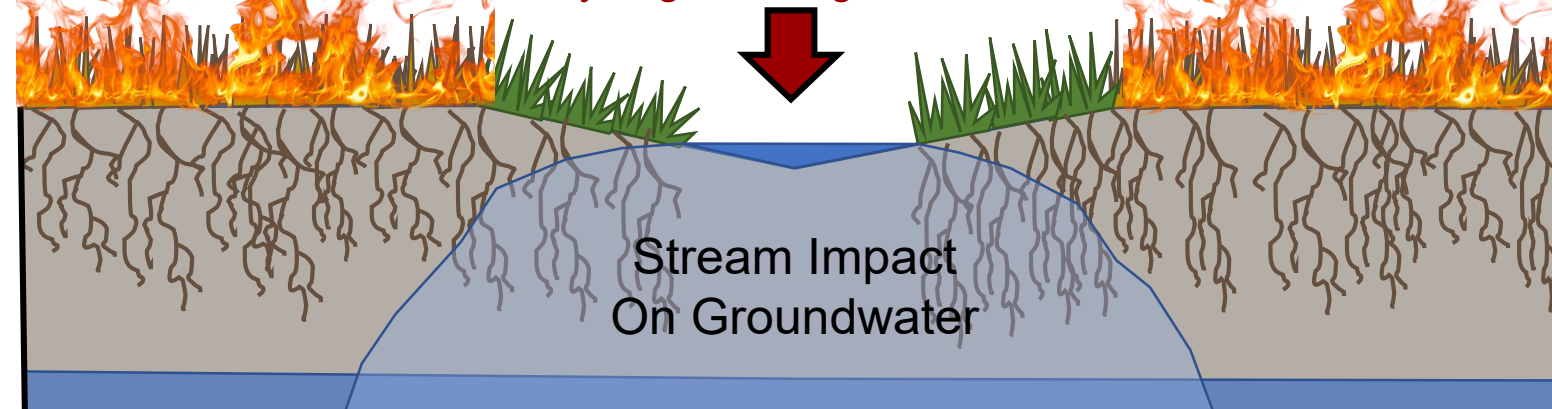
Drought Conditions

less precipitation, veg relies on groundwater



Fire Conditions

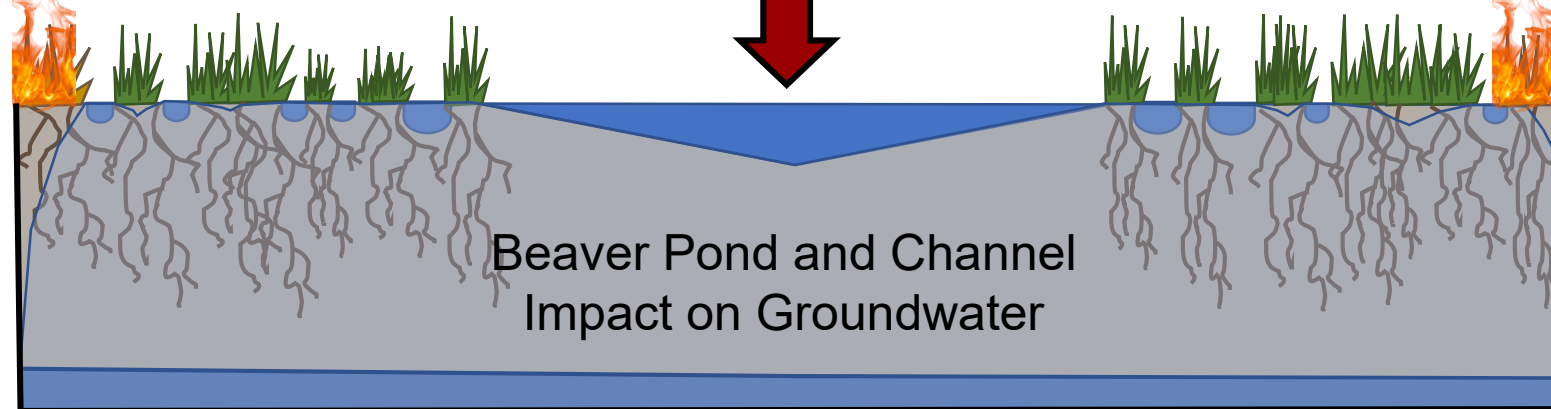
dry vegetation ignites/burns



Deep Water Table

Fire Conditions

dry vegetation ignites/burns

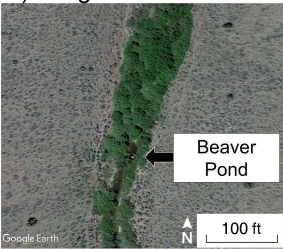


A) California: Fire
Beaver-Dammed Creek

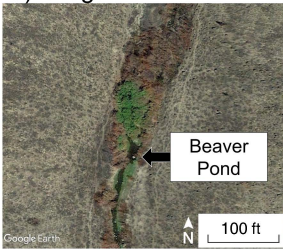
Undammed Creek



B) Oregon: Before Fire



C) Oregon: Fire

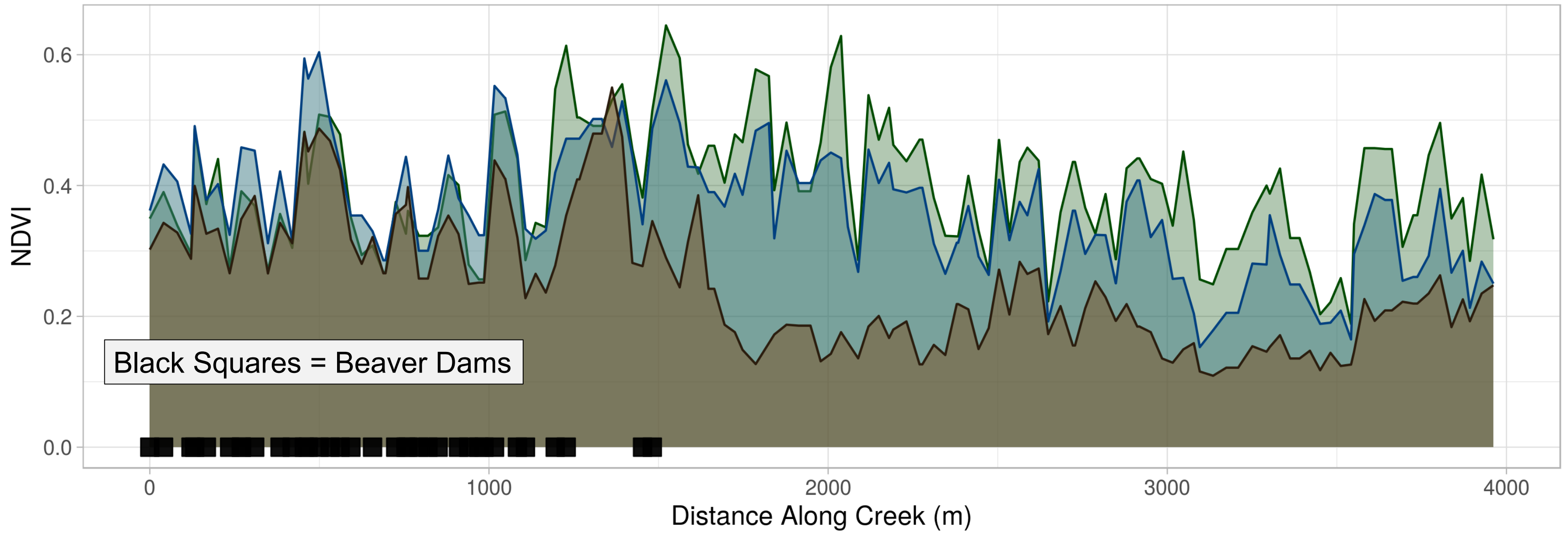


California Manter Fire Creek 1

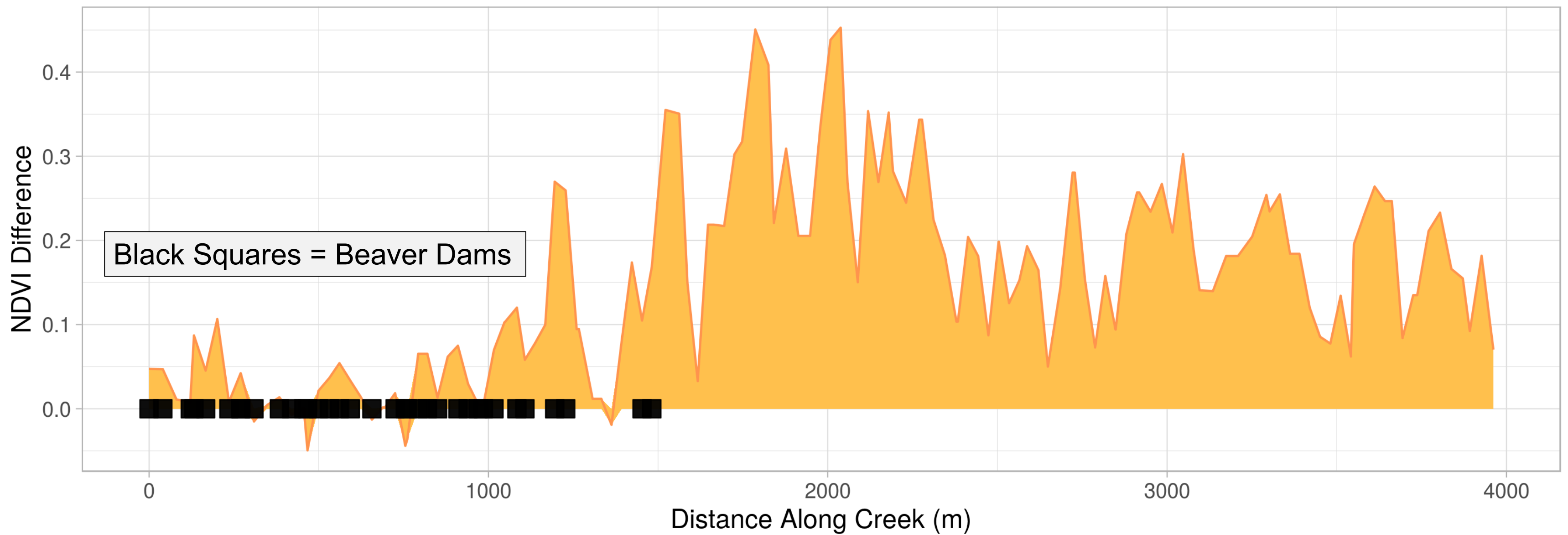
NDVI Before Fire
(July 1999)

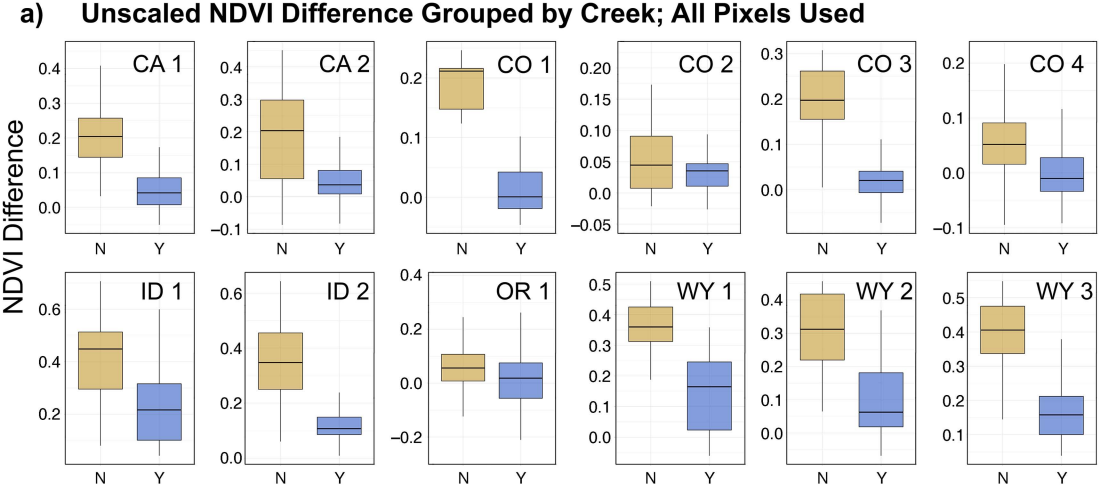
NDVI During Fire
(July 2000)

NDVI After Fire
(July 2001)

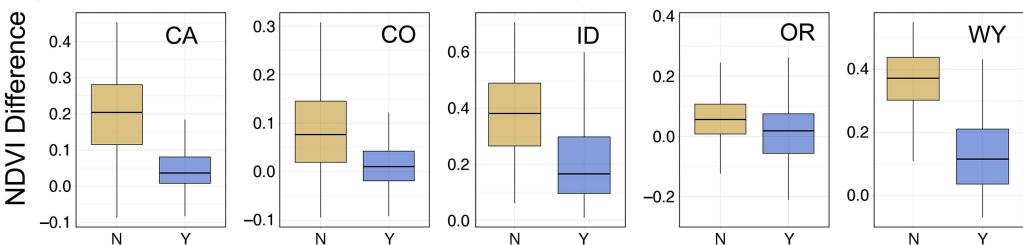


California Manter Fire Creek 1



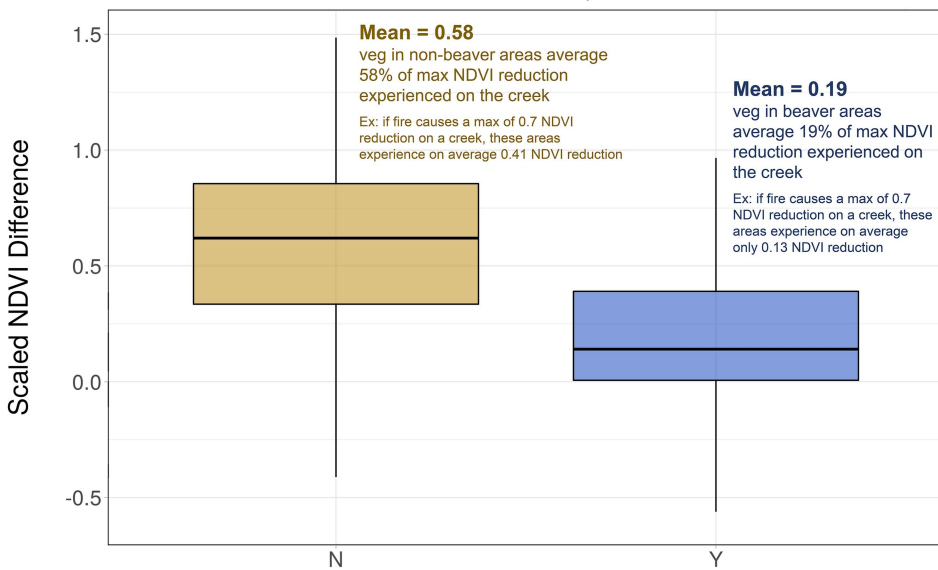


b) Unscaled NDVI Differences Grouped by Fire; All Pixels Used



c) Scaled NDVI Differences from All Fires Combined; All Pixels Used

All Data Combined: n = 1033 Pixels without Beaver; n = 1430 Pixels with Beaver



Beaver Activity: N = No (yellow); Y = Yes (blue)