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Optimizing Seed Germination in Arid Land Forbs

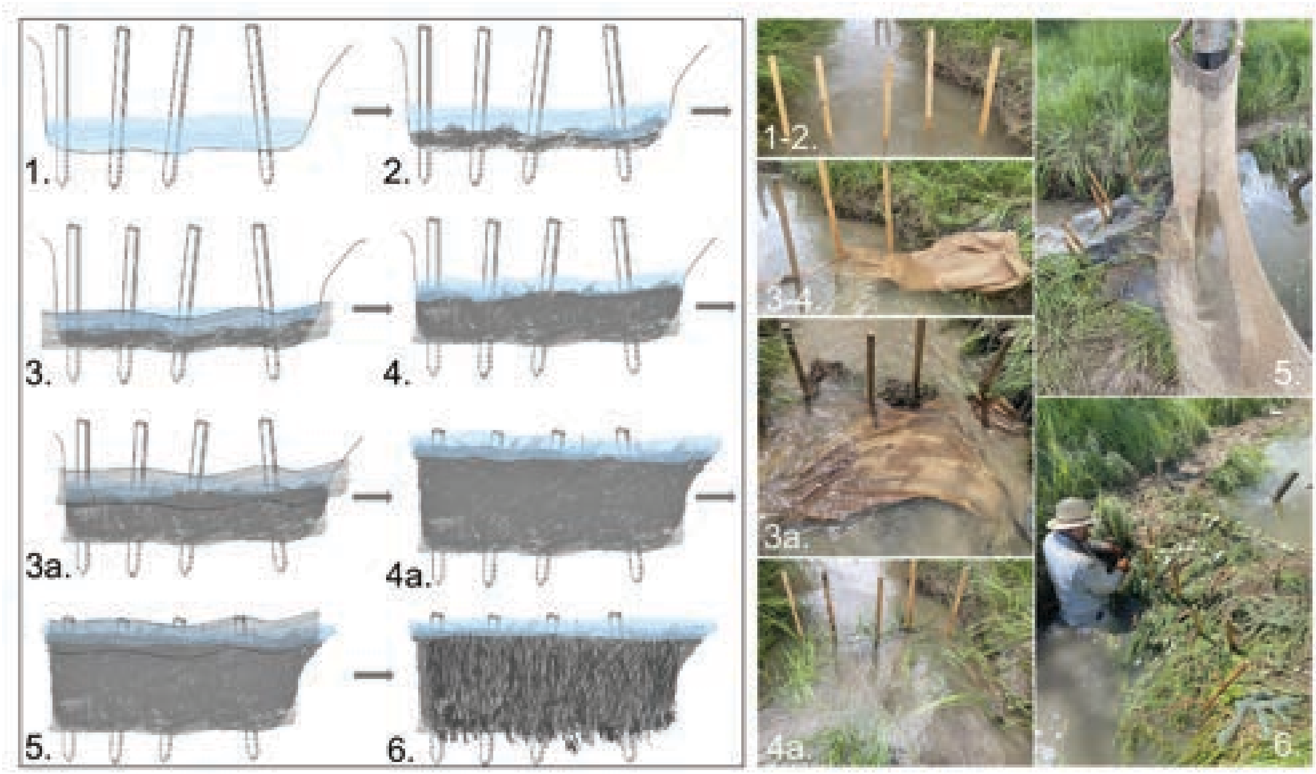

Figure 2. (left): Schematic of the six beaver dam analog construction steps for the Muddy Creek design. Narrative descriptions for each step are found in the main text. Note that 3a and 4a indicate that these two steps are repeated until the "burlap sandwich" reaches the top of the streambank. (right): Photos corresponding to the 6 steps. Note: the approximate size of the photographed structure was 1.5 meters high by 1.8 meters wide.

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Blueberry and Huckleberry Fruit Production for Wildlife Habitat Quality after Restoring Fire to Oak Forests

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Oak forests of the eastern United States were historically maintained by periodic fire (Abrams 1992, Hart and Buchanan 2012). Lack of fire since the late 1800s in many areas, however, has limited oak regeneration and facilitated prominence of shade-tolerant, mesophytic species such as *Acer rubrum* (red maple; Hutchinson et al. 2008, Nowacki and Abrams 2008, Izbicki et al. 2020). This transition from open oak habitats to more closed-canopy forests, dominated by less fire-tolerant tree species, has influenced ecosystem properties and wildlife by changing the understory microclimate (Nowacki and Abrams 2008), soil nutrient cycling (Alexander and Arthur 2014), habitat availability for ground-nesting birds (Fox et al. 2010), and quantity of mast as a food source (Rodewald and Abrams 2002).

Prescribed fire is a common management practice for the restoration and maintenance of oak-dominated ecosystems for its ability to reduce mesophytic species and create opportunities for oak regeneration over time (Brose et al. 2014, Izbicki et al. 2020). However, one of the uncertainties in using prescribed fire to restore and sustain oak-dominated ecosystems is how it may influence production of food resources for wildlife, such as fruits offered by understory shrubs (Reiners 1965, Matlack et al. 1993, Duchesne and Wetzel 2004). We sought to address this knowledge gap by examining the density and berry production after restoration of fire in eastern oak forests for three common shrubs: *Gaylussacia baccata* (black huckleberry; hereafter *Gaylussacia*), *Vaccinium pallidum* (Blue Ridge blueberry), and *V. angustifolium* (low-bush blueberry; hereafter collectively *Vaccinium*).

Gaylussacia and *Vaccinium* berries are important food sources for a variety of wildlife, including many bird species, mammals, and reptiles (Dale and Hughes 1977). The eastern box turtle (*Terrapene carolina carolina*) is one such species utilizing berries of these shrubs in eastern oak forests and is of special interest, as it is listed on the IUCN Red List as vulnerable and with declining populations (International Union for Conservation of Nature, Gland, Switzerland). *Vaccinium* and *Gaylussacia* may be a vital food source for eastern box turtles, as the turtles have demonstrated a preference for these berries (Braun and Brooks 1987) and both *Vaccinium* and *Gaylussacia* seeds have been identified in fecal samples from wild turtles (Stone and

Figure 1. Example images illustrating our study of berry production of Ericaceous native shrubs after restoring fire to oak forests in Oak Openings Preserve, northwestern Ohio, USA. Images include examples of A) igniting prescribed fires by Metroparks Toledo staff; B) an oak forest site burned six years prior, one of five burned sites where we examined berry production; and C) counting berries on *Vaccinium pallidum* (Blue Ridge blueberry), one of the study's shrub species in oak forest understories *(Image credit A: L.A. Sprow. Image credit B and C: S.R. Abella).*

Moll 2009, Figueras et al. 2021). We determined whether the abundance and berry production of *Gaylussacia* and *Vaccinium* plants differed between unburned oak forests and oak forests burned by restoration practitioners in the last six to 10 years.

Our study area was the 1737-ha Oak Openings Preserve (41°33′12″ N, 83°50′8″ W), managed by Metroparks Toledo, within the Oak Openings region, southwest of the City of Toledo in northwestern Ohio, USA. The area's climate is temperate with warm summers and cold winters. Summer precipitation (May–August) averaged 34 cm each summer from 1955 to 2023 (Toledo Express Airport weather station; National Oceanic and Atmospheric Administration, Asheville, North Carolina). Sandy soils at study sites were mapped as Udipsamments of the Oakville and Ottokee series (Stone et al. 1980). Study sites were in mature oak forest (age 100+ years), typically with 30 m^2/ha of oak basal area, and overstories contained mostly *Quercus velutina* (black oak) with some *Q. alba* (white oak; Abella et al. 2020). Until the sites receiving prescribed fire were burned, the sites had no known history of fire in at least the last 100 years.

Encompassing peak berry production, from July 16, 2024, to August 7, 2024, we measured *Gaylussacia* and *Vaccinium* stem and berry production in 10 randomly located plots in different oak forests (separated from each other by 0.1–4.1 km) in Oak Openings Preserve (Figure 1). Five plots had received a dormant-season, prescribed surface fire intended to reestablish open conditions by reducing encroaching mesophytic trees (e.g., *Acer rubrum*) in either 2018 (three plots), 2017 (one plot), or 2014 (one plot). As of 2024 sampling, time since fire ranged from 6–10 years among burned plots. The other five plots were not burned.

In each 20 m × 25 m plot, we established three, 25-m-long transects at 5, 10, and 15 m along the western side of the plots running west to east. Along each 25-m transect, we identified the ten consecutive meters with the greatest *Gaylussacia* and *Vaccinium* cover. In those ten consecutive meters, we measured stem and berry production within ten contiguous 1 m × 1 m quadrats along the transect. Within each quadrat, we counted all live stems of *Gaylussacia* and *Vaccinium*, considering each above-ground woody structure with a unique point of origin at ground level and with green leaves a live stem. We chose to count stems because both taxa can have a clonal growth form or multiple stems emanating aboveground from the root system of one individual (Matlack et al. 1993), complicating identifying genets, and our focus was on estimating berry production at the site scale and per individual stem. Also in each quadrat, we counted the number of berries on each stem. During sampling, we encountered berries of varying ripeness, with many berries ripe (black and fleshy for *Gaylussacia* and blue and fleshy for *Vaccinium*; Van der Kloet 1988) and some not yet ripe, but we counted all berries to ensure total berry production at the time of peak production was included. To simplify inventory, *V. pallidum* and *V. angustifolium* were quantified together as "*Vaccinium*," because although *V. pallidum* is taller at maturity (23–51 cm) than *V. angustifolium* (9–27 cm), the two species are similar in their growth forms (e.g., both are rhizomatous and form extensive colonies), often grow intermixed, and produce similar sized berries (Van der Kloet 1988).

We averaged data from the three transects per plot on a plot basis to calculate three metrics separately for *Gaylussacia* and *Vaccinium*: stems/m^2, berries/m^2, and the average number of berries/stem. To approximate normality and equal variance assumptions, we Box-Cox transformed the data and compared each metric between burned and unburned plots using two-sample *t* tests in PAST v. 4.17 (University of Oslo, Norway). We also calculated the percentage of stems with berries and the average berries/stem, excluding stems without berries, for burned and unburned plots. For the last two metrics, we did not apply inferential statistics because few burned plots contained appreciable stems with berries and therefore, we report descriptive statistics.

While average stem density for *Gaylussacia* did not vary significantly with burn status, berry production in terms of berries/m^2 and berries/stem were on average at least an order of magnitude higher (and significant at $p = 0.049$ and $p = 0.043$) on plots that had received prescribed fires (Figure 2). On burned sites, *Gaylussacia* produced over 5 berries/m^2 and an average of over 1 berry per stem. In comparison, on unburned plots, *Gaylussacia* berry production was minimal, averaging < 0.1 berry/m^2.

For *Vaccinium*, stem density averaged over 3× higher on burned plots, exceeding 12 stems/m^2 (Figure 2). As with *Gaylussacia*, production of *Vaccinium* berries/m^2 was an order of magnitude higher on burned than unburned plots. *Vaccinium* shrubs produced nearly 2 berries/m^2 on burned plots, contrasting with minimal production (< 0.1 berry/m^2) on unburned plots.

On average, 24.1 ± 9.7% of *Gaylussacia* stems had berries on burned plots, compared with only 1.0 ± 0.6% on unburned plots. There was an average of 4.9 ± 2.2 berries/stem for *Gaylussacia* stems with berries on burned plots, compared with only 1.9 ± 0.7 berries/stem for stems with berries on unburned plots. For *Vaccinium*, 3.0 ± 1.1% of stems had berries on burned plots, compared with only 1.8 ± 1.4% on unburned plots. Furthermore, there were over twice as many berries/stem for *Vaccinium* stems with berries on burned (2.5 ± 0.6 berries/stem) than unburned (1.1 ± 0.4 berries/stem) plots.

Our results suggest that berry production for both *Gaylussacia* and *Vaccinium* is higher in burned compared to unburned oak forests and that the two taxa achieved this increase in different ways. *Gaylussacia* stem density was not significantly different between burned and unburned plots, but orders of magnitude higher percentages of stems

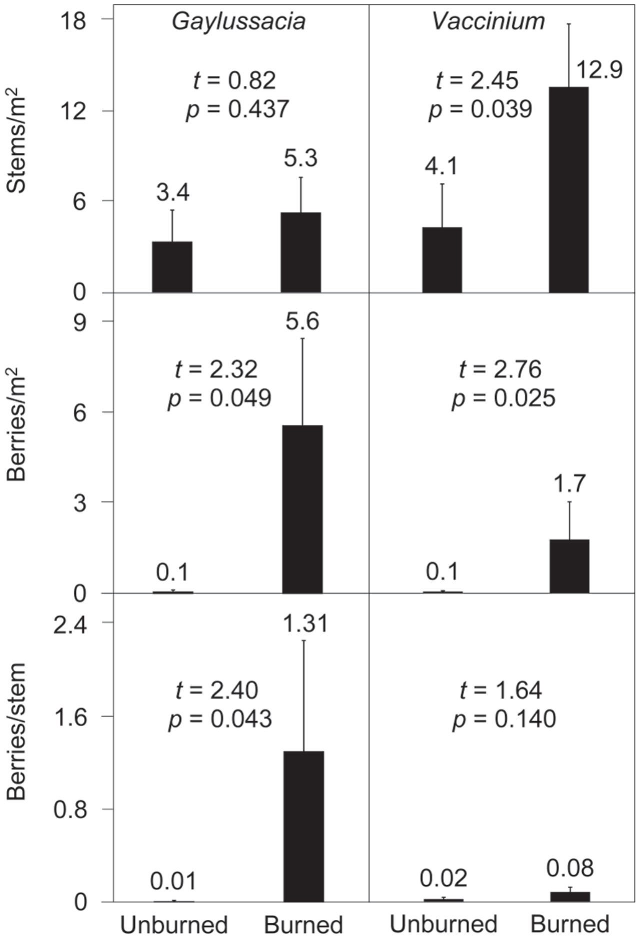

Figure 2. Abundance of berry-producing, native shrubs and berry production density compared in oak forests unburned or receiving a prescribed fire in the last 6–10 years, Oak Openings Preserve, northwestern Ohio, USA. Data are means (+ 1 standard error of means as error bars, with means listed at the top of bars), compared using *t* tests (8 degrees of freedom) for each species and metric. The shrub species are *Gaylussacia baccata* (black huckleberry) and *Vaccinium* (including *V. pallidum* [Blue Ridge blueberry] and *V. angustifolium* [lowbush blueberry]).

producing berries and more berries/stem on burned plots led to the increased berry production per unit area of forest. In comparison, *Vaccinium* had a significantly greater density of stems on burned plots and moderately higher percentages of stems with berries and number of berries/stem. This different combination also produced higher berry production per unit area in burned forests.

Above average rainfall occurred in the months leading up to the study, but this is not unusual because early summer rainfall has been increasing since the early 1990s (Abella et al. 2025). Precipitation from May through June 2024 was 132% of the long-term average (1955–2024) for these months (Toledo Express Airport weather station; National Oceanic and Atmospheric Administration, Asheville, North Carolina). As both burned and unburned forests experienced this climate, restoration of fire appeared to be the driving factor for berry production in oak forests in our study. Our results are further supportive of prior studies in other ecosystems where post-fire habitat was favorable for *Gaylussacia* and *Vaccinium* once burned plants recovered. For example, Duchesne and Wetzel (2004) found that prescribed fires of low intensity maximized *V. angustifolium* and *V. myrtilloides* berry production in an Ontario, Canada clear-cut pine community. Matlack et al. (1993) determined that both fire and clipping promoted *G. baccata* growth in the New Jersey pine barrens. Pengelly and Hamer (2014) also concluded that *V. scoparium* berry production increased after prescribed fires in conifer forests in Banff National Park, Alberta, Canada.

To better understand the relationship between prescribed fire and berry production of shrubs in oak forests, future research could examine the post-fire mechanisms of change (e.g., greater light from reduction of the tree canopy or sub-canopy, changes to soil nutrients, decreased leaf litter, direct effect of fire) as well as how stem and berry production may change over time. Due to the limited number of burned sites available, we were unable to examine the effect of time since fire or seasonality of fire on *Gaylussacia* and *Vaccinium* production. There is some evidence that extremely frequent fires (e.g., more frequent than every three years) can reduce *Gaylussacia* cover, suggesting that time for recovery after fire is required before plants increase berry production (Reiners 1965). Our 6–10-year, post-fire timeframe allows time for plant recovery and production, but it does not indicate exactly when a post-fire increase in berry production occurs, or if/when production returns to unburned levels. It may be useful from a restoration management perspective to establish how long after fire any effects last to determine the frequency of burns required to maintain elevated berry production where that is a goal.

We found that berry production per unit area was an order of magnitude greater in oak forests where restoration practitioners had reintroduced fire. Our results suggest that in addition to providing other ecosystem benefits, reintroducing fire to oak forests can stimulate production of food sources important to a variety of wildlife.

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