# Drill-Seeding Blue Oak Acorns: Testing the (Cost-)Effectiveness of a New Restoration Technique across Years and Microsites

*Alex Palmerlee (corresponding author: P.O. Box 578 Bangor, CA 95914) and Truman P. Young (Department of Plant Sciences, University of California, Davis, CA)*

In both cleared and existing *Quercus douglassii* woodlands, there is a perceived lack of recruitment (Adams et al.1992, Swiecki and Bernhardt 1998, Koenig and Knops 2007). There are many factors that appear to limit blue oak recruitment, including cattle, annual grasses, rodents, deer, climate change, and fire regime (McCreary 2001). Traditional restoration methods focus on planting techniques that control for many of these factors via irrigation, container stock, tubes, fencing, and weed control (Brooks and Merenlender 2001). The limitation of this approach is that the cost/acre of a typical restoration project is too high to implement on a landscape scale and may be insufficient to mitigate for or reverse the current and future loss of extant oak woodlands (Standiford et al. 2002). The range of blue oaks covers some three million hectares across California (Bollsinger 1988). Challenges facing this ecosystem, including those posed by climate change, demand that we develop new, more cost-effective, techniques that can be applied on hundreds or thousands of hectares per year with the same limited restoration dollars.

Although many restoration projects report on techniques and interventions that are "effective" (i.e., increase seedling survival or cover), they rarely quantitatively weigh these against their costs, which can be considerable. Estimates of cost effectiveness (dollars per established seedling or per percent cover) date back at least 25 years (Bainbridge 1995) but are still rare (Kimball et al. 2015).

While drill-seeding is a common practice for smaller-seeded species, it is not a common technique for larger-seeded woody species. Our previous research demonstrated that direct (hand) seeding of woody plants is more cost effective (dollars per surviving plant) than container planting, particularly with large-seeded species (Palmerlee and Young 2010). We set out to build on our previous research to develop and quantify the cost-effectiveness of a novel drill-seeding technique, and to do so in different landscape contexts to provide greater direction for land managers.

doi:10.3368/er.40.1.25
*Ecological Restoration* Vol. 40, No. 1, 2022
ISSN 1522-4740 E-ISSN 1543-4079


## Study Site

Far View Ranch is a 400-hectare cattle ranch in the foothills of the Sierra Nevada mountains. Elevation ranges from 60–150 meters and soils are a Dunstone-Loafercreek Complex (Ultic Haploxeralfs) (California Soil Resource Lab 2010). The vegetation is blue oak savanna, varying in density from approximately 5–20 trees/ha, with an understory dominated by non-native annual grasses. Stocking rate, as described by the rancher, is one animal unit per four hectares (1 AU per 8 acres).

## Methods

In December of 2018, we set up 32, 30 × 2.5 meter (100 × 8-foot) planting sites at Far View Ranch, eight replicates of all four treatments (Figure 1). (Two of these planting sites were miss-planted and were removed from the dataset.) Each planting site was disced in three passes to uniform bare soil using a 2.5 meter (8-foot) wide tandem disc two-weeks after the first germinating rains. To plant the acorns, a tractor pulled the seeding implement with the planting shank down the center of the disced area. A second person walked alongside and dropped 36 acorns into the planting tube of the drill-seeder. Acorns were collected in September and refrigerated in sealed plastic bags filled with moist vermiculite.

Four-wire cattle fencing was constructed around No Cattle treatments. Seeding sites where cattle had access were planted adjacent to these exclosures. Shaded sites were installed under oak canopies where we estimated

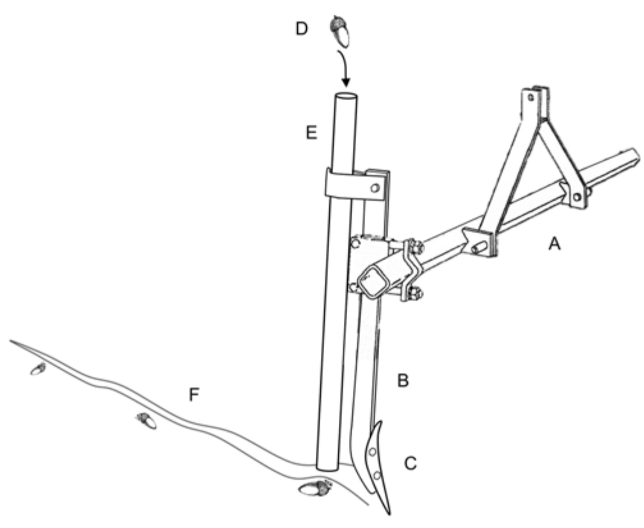


**Figure 1. A tractor pulls a standard three-point hitch with toolbar A). Clamped to the toolbar is a metal shank B) with attached ripping tooth C). An acorn D) is dropped into the 5-cm (2-inch) metal planting pipe E). The acorn falls through the pipe and into the planting furrow F) and the soils slumps over the acorn as the implement passes, effectively burying or "drill seeding" the acorn.**

that seeds would be in shade 80% of the day. Unshaded sites were located in open rangeland (Figure 1). To account for naturally recruiting acorns, we monitored two control transects, parallel to the planted transect and within the disced area. Replicates with natural recruitment in the control transects were removed from the dataset. (In the 2018 planting, three No Cattle + Shade replicates were removed from the dataset either because the planting lines were not distinguishable or due to natural recruitment found during the monitoring of control transects.)

A second planting was installed in late December of 2019 in an additional 60 planting sites (15 replicates/treatment) within and adjacent to the existing fenced paddocks from the previous year's plantings. These were drill-seeded with 30 acorns per transect. Finally, each of the 2019 transects were divided into four sections and alternately sprayed and left untreated in February of 2020 with 1% glyphosate herbicide. (Due to low year-2 acorn emergence (see below), there were insufficient data to analyze herbicide impact.)

Seeded and control transects from both seasons were monitored in the late spring following planting to capture seedling emergence. Monitoring consisted of walking each 30-meter planting and control transect three times, carefully examining for emerging/surviving seedings. Any oaks found within the planting line were marked with a pin flag for continued monitoring. Follow-up monitoring occurred after each summer for two years.

### *Statistical Analyses*

The numbers of survivors after the first year were converted to proportions surviving for each planting transect (replicate). There were 36 acorns planted in each row in 2018, and 30 per transect in 2019. These proportions (survivorships) were arcsine-square root transformed for statistical analysis. We ran an ANOVA for the effects on (transformed) survivorship of seeding year, cattle, shade, and the interaction of cattle and shade.

## Results

Our tested drill-seeding technique produced first-year survivorships of up to 20% in favorable years and microsites (Figure 2). First-year survivorship was significantly lower in the 2019 seedings than in the 2018 seedings (2.3% vs 12.9%, $p < 0.001$, Table 1, Figure 2). The presence of cattle tended to reduce survivorship, but this was particularly pronounced in the shaded sites (Cattle x Shade interaction: $p = 0.03$; Table 1, Figure 2).

Of the 972 acorns from the 2018 seeding, 125 seedlings emerged. 2018 was a notably wet year, with over 106.7 cm (42–inches) recorded between September 2018 and October 2019. This is compared to 41.9 cm (16.5-inches) of recorded rainfall in 2019–2020 according to The Western Regional Climate Center (WRCC 2020a). The WRCC describes the 50-year average annual rainfall for the region as 73.2-cm per year (28.8-inches; WRCC 2020b). Survival of these emerged seedlings was over 50%, which we attributed to the wet winter. The lowest survival rates came in the replicates with Cattle + Shade. Only 5.6% had seedlings in Year 1, dropping to 2.1% in Year 2. This is likely because of cattle tendency to congregate under oak trees for shade.

In 2019, the project was implemented at a larger scale. However, 2018–19 was a poor mast year, with no acorns found on Far View Ranch and only an exhaustive search of adjacent properties yielding enough seeds for the study. Compounding this was an extremely dry winter with a notable seven week drought spanning January–early March, the period when acorns have germinated and are sending down a taproot. Of the 1,800 acorns planted in 2019 across all 60 transects, only 42 individuals emerged (2.3%). Of these seedlings, 25% survived through the first summer.

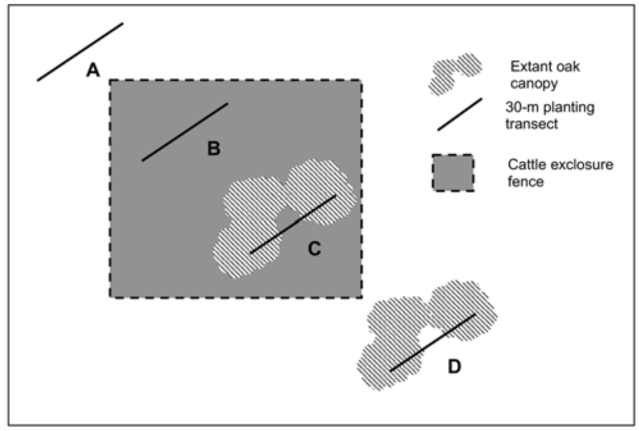


**Figure 2. Experimental design showing planting transect, cattle exclosure, and shade canopy. Treatments: A) Cattle + No Shade, B) No Cattle + No Shade, C) No Cattle + Shade, and D) Cattle + Shade.**

**Table 1. Results of ANOVA on first-year survivorship (arcsine-square root transformed).**

| Source | DF | Sum of Squares | F ratio | P |
|---|---|---|---|---|
| Seeding year | 1 | 0.209 | 37.43 | *< 0.001* |
| Cattle | 1 | 0.027 | 4.76 | *0.03* |
| Shade | 1 | 0.001 | 0.15 | *0.70* |
| Cattle x Shade | 1 | 0.026 | 4.74 | *0.03* |
| Error | 67 | 0.395 | | |

## Discussion

### *Low Oak Survival*

Our results add limited resolution to the story of recruitment in blue oak woodlands that remains largely unclear (Koening and Knops 2007). Our results seem to confirm

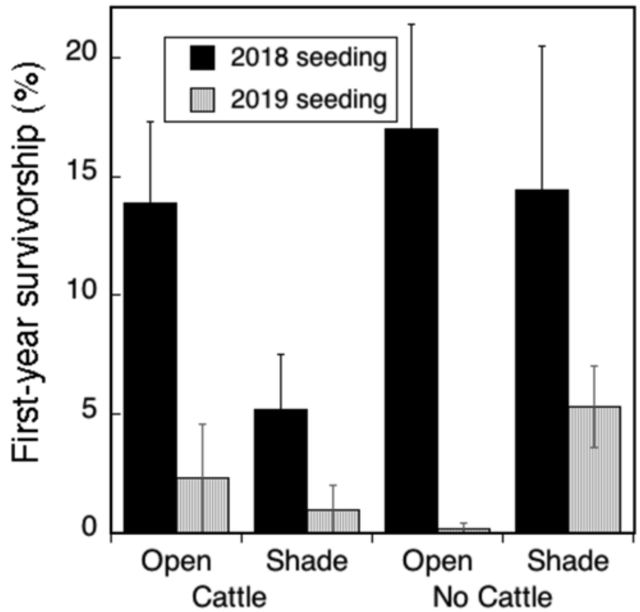


**Figure 3. Survivorship data and error bars representing standard error after one year, for both planting seasons, across all treatments.**

what we see anecdotally in field settings, where many seedlings are present after a mast year but none are able to reach the sapling stage. This tendency toward die-off was true in treatments with cattle, but also in our "high performing" Shade + No Cattle treatments, where the buildup of grass thatch often created a dense matting, possibly too difficult for seedlings to push through. This suggests that complete removal of cattle is not a simple solution due to interactions with grass production and competition. In extant woodlands, a management solution supporting natural recruitment, not restoration, is likely to be more cost-effective. Further work is needed to study where oaks are recruiting naturally, quantify those ideal field conditions, and test the efficacy of recreating those conditions across the landscape.

### *Effects of Cattle and Landscape Features*

The negative effects of cattle on oak recruitment (Figure 2) were almost entirely due to the shaded sites where they had access. Cattle congregated in the shaded planting sites due to the low-density of oak cover across the landscape (pers. obs.), often leaving those areas completely bare. Cattle absence seems to also have a detrimental impact on recruitment as we noted in many planting sites, where the grass production was so intense in the wet 2018–19 season (Figure 2). However, in our 2019–20 planting, shade became highly positive in the absence of cattle, presumably because of reduced grass growth with reduced rainfall. As in the wet year, cattle still had a more-negative impact on shaded compared to non-shaded planting sites.

### *Effectiveness of Drill Seeder*

The major restoration challenge we sought to study was bringing oaks back into empty rangelands, where shade and seed from mature trees are absent. Our results suggest that fencing areas off from cattle and planting them with a large-scale planting technique may be sufficient. Certainly, if the alternative is hand planting without post-planting interventions (tree shelters and irrigation), drill-seeding should be seen as far more cost-effective.

As with any new technique, more work is needed to develop a list of best-practices. Testing planting depth or timing could maximize acorn emergence; adding a planting shank to the implement toolbar could double the amount of acorns planted/hour (Figure 1); focusing on favorable microsites could improve seedling survival. As drill-seeding is used by farmers, ranchers, and land-managers, it will be fine-tuned, adapted, and repurposed to increase cost-effectiveness and suit diverse situations.

### *Cost-Effectiveness*

Adding cost as a factor in success is key to understanding the efficacy of drill-seeding as a restoration tool. As we expected, the very low survival is offset by lower planting costs compared to traditional methods. All cost calculations are based on survival data of the 2018–19 planting after two summers. Assuming that hand-planted acorns, without any additional interventions, have the same post-planting survival rates (i.e., there is no inherent negative relationship of drill-seeding and emergence or survival), then drill-seeding is 2.6-times more cost-effective than hand-planting (Table 2). To be as or more cost-effective than drill-seeding, adding the costly interventions of tubes and irrigation, the current standard, a restorationist would need to see 60% survival or better after two summers (without replanting) (Table 3.).

### *Year Effects*

Year effects matter and point to the merits and drawbacks of lower cost/planting techniques. Because restoration funding is often linked to a calendar, not field conditions, restorationists often bypass extreme interannual variations with interventions such as irrigation to ensure high success. Because this drill-seeding approach requires no follow-up maintenance (as there would be if individual plants were tubed or irrigated) the implementation calendars could be scheduled to align with high masting years.

It's possible that, even in dry years, low-cost seeding is worth the time as survivors will then be selected for drought-tolerance. Indeed, while the success of the second-year planting was low, with only 2.33% emergence, 25% of those individuals survived a first summer without supplemental interventions, suggesting that seeding mass numbers of acorns may be worthwhile, even in a dry year. Because acorns are relatively cheap, compensating for high

**Table 2. Cost estimates for various planting methods.**

| | Task | Cost/Unit | Labor Cost/Hr | Hrs/Plot | Cost/Line |
|---|---|---|---|---|---|
| Drill Seeding | | | | | |
| | Discing | $40.00 | S40.00 | 0.067 | $5.36 |
| | Planting | $40.00 | S60.00 | 0.016 | $1.60 |
| | Sum of costs | | | | $6.96 |
| Hand planting with interventions | | | | | |
| | Clearing thatch | | $20.00 | 0.6 (hrs) | $12.00 |
| | Planting | | $20.00 | 0.75 (hrs) | $15.00 |
| | Irrigation | | $20.00 | 5 (hrs) | $100.00 |
| | Tubes | $3.00 | | 36 | $108.00 |
| | Stakes | $0.20 | | 36 | $7.20 |
| | Irrigation | $0.10 | | 100 (ft) | $10.00 |
| | Emitters | $0.20 | | 36 | $7.20 |
| | Sum of costs | | | | $247.40 |
| Hand planting without interventions | | | | | |
| | Clearing thatch | | $20.00 | 0.3 (hrs) | $6.00 |
| | Planting | | $20.00 | 0.6 (hrs) | $12.00 |
| | Sum of costs | | | | $18.00 |

**Table 3. Cost effectiveness by planting year across all treatments.**

| | Treatment | Total Survival | Survival/ 30m | Drill Cost/ Survivor | Interventions Cost/80% | Interventions Cost/60% | Hand Planted Cost Equivalent | Cost ratio |
|---|---|---|---|---|---|---|---|---|
| 2018–2019 Planting | | | | | | | | |
| | CNS | 0.020 | 0.714 | $9.74 | n/a | n/a | $25.20 | 2.59 |
| | CS | 0.003 | 0.125 | $55.68 | n/a | n/a | $144.00 | 2.59 |
| | NCNS | 0.017 | 0.625 | $11.14 | $8.59 | $11.45 | $28.80 | 2.59 |
| | NCS | 0.021 | 0.750 | $9.28 | $8.59 | $11.45 | $24.00 | 2.59 |
| 2019–2020 Planting | | | | | | | | |
| | CNS | 0.002 | 0.056 | $125.28 | n/a | n/a | $324.00 | 2.59 |
| | CS | 0.004 | 0.111 | $62.64 | n/a | n/a | $162.00 | 2.59 |
| | NCNS | 0.003 | 0.083 | $83.52 | $10.31 | $13.74 | $216.00 | 2.59 |
| | NCS | 0.019 | 0.583 | $11.93 | $10.31 | $13.74 | $30.86 | 2.59 |

mortality by mass-planting techniques such as drill seeding can be cost-effective.

When faced with issues impacting entire ecosystems, restoration should seek new techniques applicable at a large spatial scale. While climate change threatens to create massive shifts in current plant distribution, it makes focus on developing scalable techniques more critical. Drill seeding is a common technique for small-seeded species but our results suggest that drill-seeding of large-seeded species has potential and should be considered as another technique for testing and use in the restoration tool kit.


## Acknowledgments

The Natural Resources Conservation Service provided invaluable funding for this project both through their EQIP and Western SARE programs. Thanks also to Carrie Wendt of Point Blue Conservation Science and our rancher, Dave Daley.


## References


Adams, T.E. Jr., P.B. Sands, W.H. Weitkamp and N.K. McDougald. 1992. Oak seedling establishment on California rangelands. *Journal of Range Management* 45:93–98.

Bainbridge, D.A., M. Fidelibus and R. MacAller. 1995. Techniques for Plant Establishment in Arid Ecosystems. *Restoration & Management Notes* 13:190–197.

Bollsinger, Charles L. 1988. *The hardwoods of California's timberlands, woodlands, and savannas*. Res. Bull. PNW-RB-148. Portland, OR: Pacific Northwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture.

Brooks, C.N. and A.M. Merenlender. 2001. Determining the pattern of oak woodland regeneration for a cleared watershed in northwest California: A necessary first step for restoration. *Restoration Ecology* 9:1–12.

California Soils Resource Lab. SoilWeb soil survey for the study location. casoilresource.lawr.ucdavis.edu/gmap/?loc=39.37151, -121.44030.

Kimball, S., M. Lulow, Q. Sorenson, K. Balazs, Y.-C. Fang, S.J. Davis, et al. 2015. Cost-effective ecological restoration. *Restoration Ecology* 23:800–810.

Koenig, W.D. and J.M.H. Knops. 2007. Long-term growth and persistence of blue oak (*Quercus douglasii*) seedlings in a California oak savanna. *Madroño* 54:269–274.

McCreary, D. 2001. *Regenerating Rangeland Oaks in California*. University of California Agriculture & Natural Resources. Publication 21601e.

Palmerlee, A.P. and T.P. Young. 2010 Direct seeding is more cost-effective than planting container stock across ten woody species in California. *Native Plants Journal* 11:89–102.

Standiford, R.B., D. McCreary and W. Frost. 2002. Modeling the effectiveness of tree planting to mitigate habitat loss in blue oak woodlands. in: Proceedings of the Fifth Symposium on Oak Woodland: Oaks in California's Changing Landscape, October 22–25, 2001, San Diego, CA. USDA Forest Service General Technical Report PSW-GTR-184. pp. 591–600.

Swiecki TJ, Bernhardt E (1998) Understanding blue oak regeneration. *Fremontia* 26:19–26.

Western Regional Climate Center (WRCC). 2020a. RAWS climate data recorded at Bangor, California. wrcc.dri.edu/cgi-bin/rawMAIN.pl?caCBGR.

Western Regional Climate Center (WRCC). 2020b. Average rainfall data recorded at Oroville, California. wrcc.dri.edu/cgi-bin/cliMAIN.pl?caorov+nca.

## Innovation in Restoration: Estimating Seed Counts Using a Photography App

*Samantha Kelly (Department of Environmental Science and Management, Humboldt State University, Arcata, CA), Cessair McKinney (Dpartment of Environmental Science and Management, Humboldt State University, Arcata, CA) and Kerry M. Byrne (corresponding author: Department of Environmental Science and Management, 1 Harpst St., Arcata, CA 95521, kb33@humboldt.edu)*

Native seeds are a key resource for restoration programs worldwide. Despite their importance, basic information about native seeds such as germination rates and viability are not available for most native plant species used in restoration projects. Recent efforts have focused on formulating a methodological framework for native seed quality assurance standards to ensure global restoration projects are successful (Gann et al. 2019, Frischie et al. 2020, Pedrini and Dixon 2020).



doi:10.3368/er.40.1.29
*Ecological Restoration* Vol. 40, No. 1, 2022
ISSN 1522-4740 E-ISSN 1543-4079


Basic to our knowledge of native seeds is enumerating the total number of seeds present for a given species and conducting germination trials so that practitioners can successfully plan and execute restoration projects using the proper quantity of seeds. For commonly used "workhorse" species (Erickson 2008), information on seed purity, germination, and 1,000 seed weight may be available from the Kew Seed Information Database (Royal Botanic Gardens Kew, 2021) or other published sources. However, restoration projects often use at least several species for which little is known about seed weight or germination rates. Furthermore, wild seeds may be variably sized within a single site or across their geographic range (Pedrini and Dixon 2020) so that information from one project may not be transferrable to a project using the same species pool in a different geographic region.

There is a need for more basic information about native seeds, yet manually counting seeds and conducting germination trials is time intensive and therefore expensive. In the past decade, there has been an increase in the use of digital imaging technology in agricultural disciplines to decrease the time and labor involved in quantifying seeds. Studies indicate that several forms of digital image analysis can accurately enumerate seeds and assess other key seed traits for agronomic species such as maize, wheat, barley amaranth, and rice (Severini et al. 2011, Mussadiq et al. 2015, Wu et al. 2020, Bertucci et al. 2020). However, agronomic species are typically bred for large, uniform seeds which are likely much easier to identify in images. Can digital image analysis be used in restoration projects to quickly enumerate native seeds for direct planting, germination trials, or other uses? To our knowledge, there has been little research on the success of photo counting software for counting small and variably sized seeds such as the ones that are frequently used in restoration.

CountThings From Photos (Dynamic Ventures Inc., Cupertino, CA, USA) is an app that uses computer vision, a field of artificial intelligence to analyze static digital images and quantify the number of objects contained in the image. The app uses counting templates that are trained for a specific object, such as pipes, livestock, plants, or insect larvae. The app includes an adjustment tool that allows users to manually adjust count estimates. It is easy to install and use on a smart phone or personal computer using photos that you take in real time with the app or existing photos that were taken with a phone or digital camera. It can be downloaded for a week-long trial period for no cost, or by daily, monthly, or yearly licenses with costs ranging from $20 for one day to $1000 for an annual license for one device. CountThings has the potential to decrease the amount of time spent counting seeds for restoration projects, but has not yet been tested. The objective of our research was to test the ease, accuracy, and time investment required to