Direct seeding optimization: an experimental approach to building resilient forests of threatened whitebark pine in the Greater Yellowstone Ecosystem

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Background and Objectives

Whitebark pine (*Pinus albicaulis*; WBP) populations are in widespread decline across their range due to the invasive exotic pathogen white pine blister rust (*Cronartium ribicola*; WPBR), mountain pine beetle outbreaks (*Dendroctonus ponderosa*), altered fire regimes, and range shifts, all of which are accelerating with climate change (Tomback and Achuff 2010, Parks *et al.* 2025). WBP was placed on the Endangered Species List as a *threatened* species in 2023 (USFWS 2022). Given the rapid rate of decline, it is critical that land managers implement WBP restoration expeditiously, as losses due to inaction could be irreversible. A key restoration action is to increase the frequency of trees resistant to WPBR. One strategy is to plant WBP seedlings that are likely to have genetic resistance to WPBR (based on screening trials) (Pansing and Tomback 2026). However, seedling planting is not generally approved for restoration in Wilderness Areas under the Wilderness Act (Boerigter *et al.* 2025), and modeling indicates that 75% of climate-suitable WBP habitat will occur in designated Wilderness areas (including national parks) as the climate warms (Parks *et al.* 2025). Additionally, seedling planting often requires the use of pack stock, large crews, and/or helicopters to transport seedlings and the supplies necessary to plant them.

For these reasons, a more efficient and cost-effective method of restoration is by direct seeding of WPBR-resistant seeds. Field personnel can hike further into the backcountry with all the necessary supplies and thousands of seeds in a backpack. Additionally, direct seeding has gained acceptance for use in many nominated and legislated Wilderness Areas in national parks and national forests. Both Yellowstone National Park (YELL) and Grand Teton National Park (GRTE) began implementing direct seeding pilot treatments in 2023. The preliminary results, however, show that the germination success of these treatments has been below 20%. This is due to a high rate of seed pilferage by small mammals and poor seedling survival. We propose research to optimize the direct seeding method by studying which variables limit animal pilferage and increase germination success.

The direct seeding treatments previously conducted across more than 78 acres in YELL and GRTE combined focussed on the following research questions:

1. Is germination more successful when seeds are cached near a protective object versus in the open? Does a protective object increase seed pilferage?
2. Seeds are experimentally cached at different densities – 320, 125, and 60 caches per acre. Does pilferage decrease with lower cache densities?
3. Are seeds cached on different aspects and slopes experiencing different rates of germination?
4. Does higher percent cover of vegetation impact germination?
5. Does pre-deployment seed stratification speed up or increase germination rate?
6. Are seeds greater than 10 years old germinating at the same rate as seeds less than 10 years old?

We plan to continue investigating these questions and build upon them by incorporating germination trials to analyze the viability of the seeds previously deployed as well as those used in future treatments. Previous treatments used “new” seeds that were less than 10 years old and “old” seeds that were greater than 10 years old because managers at both YELL and GRTE were curious if seeds over 10 years old remained viable. The answer to this question could help inform managers on the best use of “old” seeds

that are currently in storage. The primary purpose of this study, however, is to determine the success of seeds being deployed via direct seeding, so in order to differentiate between seeds that were unsuccessful due to age versus seeds that were unsuccessful due to pilferage, future treatments will eliminate this variable, i.e. not use "old" seeds in the field. Germination trials of all seeds used will be conducted in a controlled environment in fall 2026 and spring 2027.

Study Plan and Methods (Summer 2026)

The direct seeding methods of this study are based on Pansing *et al.* (2017). The seeding sites are in YELL and GRTE WBP Core Areas, which are incorporated in the *National Whitebark Pine Restoration Plan,* where WBP stands have been decimated by WPBR, mountain pine beetles, and/or fire (Tomback and Sprague 2022). Additionally, seeding sites were identified as climate resilient based on fine-scale climate modeling conducted by the NPS Inventory & Monitoring Division's Greater Yellowstone Network and Huysman (2025).

In 2026, a new treatment will be deployed in YELL, which will consist of 9 1-acre blocks; three blocks of each cache density (320, 125, and 60 caches/ac). Aside from the addition of a new cache density in 2025 and the removal of the seed age variable in 2026, the following methods are unchanged from the methods of the previous direct seeding trials deployed in 2023-2025. Random points are generated for each cache location and randomly assigned whether the cache is placed next to a protective object or in the open. A portion of caches, selected at random, are marked to monitor during the two years following sowing. The monitored cache sites are characterized by aspect, slope, protective object type (rock, log, dead or live trees), dominant vegetation type (herbaceous, litter, graminoid, bryophyte, none), dominant vegetation species, and vegetation percent cover. One year following sowing, all the marked caches will be revisited, and data will be recorded regarding whether 1, 2, or none of the seeds have germinated, whether the cotyledon seedlings are alive or dead, and whether ungerminated seeds remain or are completely missing, indicating that they may have been pilfered. The team will also note whether seed coats were found ,which indicates that the seeds were unsuccessful—either germinated and died, or were pilfered. The monitoring procedure will be repeated in the second year following sowing, at which point all monitoring markers will be removed from the site. Additionally, during the 2026 field season, we will be monitoring five treatments in YELL and GRTE that were deployed in 2024 and 2025.

After two years post-deployment, monitoring is complete and the data will be analyzed, with outcomes leading to the optimization of the direct seeding restoration method. Data will be analyzed, if adequately robust, by multi-variate modeling (e.g., GLMM), to examine the most important variables contributing to seeding success.

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