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Innovation in Restoration: Estimating Seed Counts Using a Photography App

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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).

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

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use the CountThings app to estimate the number of seeds in a sample.

We selected two sagebrush species, *Artemisia cana* (silver sagebrush) and *A. arbuscula* (low sagebrush) as our species of interest for this study. Sagebrush seeds are used in many restoration projects in western North America. They are small and variably sized (individual seed mass ranged from 0.09–0.31 mg, authors' unpub. data), which is typical of many native plants (Baskin and Baskin 2007). We collected wild sagebrush seeds near Gerber Reservoir, Oregon, USA by fastening a mesh seed collection bag over individual sagebrush stems in the early summer then collecting the mesh bag once fruits reached maturity in September 2019. We separated seeds from inert material by hand. For this analysis, we cleaned seed from a total of 50 samples (stems) and did not distinguish between the seeds of the two sagebrush species in our analysis. We placed the clean seeds from each sample on a piece of 22 × 28 cm white paper. We first spread the seeds across the white paper (taking care to generally separate the seeds) and manually counted them, then photographed the paper using an Apple iPhone 11 with a standard 12-megapixel camera.

In our initial analysis, we tested many existing templates in CountThings, and found that three were fairly accurate in estimating the number of sagebrush seeds in a photograph (Figure 1). These templates were: Baby Tilapia Fingerlings, Cattle, and Potato Cyst Nematodes. However, after consultation with a representative from CountThings, we collaborated with the company to create our own template that was trained specifically on sagebrush seed images. This template is now available on the CountThings website and is called Sagebrush Seeds. It took about a week for CountThings to create the customized template. For each sample, we used the same digital image to estimate the number of seeds using the four templates (Baby Tilapia Fingerlings, Cattle, Potato Cyst Nematodes, and Sagebrush Seeds). We did not use the optional adjustment tool to increase accuracy for any of these samples.

We assessed the accuracy of each template using simple linear regression, with the actual number of seeds as the x variable and the estimated number of seeds by each template as the response variable. We assumed the model with the greatest R^2 value and slope closest to 1 was the most accurate. We forced the regression through the origin for the most accurate model since a photograph with no seeds on it should produce an estimate of 0 seeds (Cochran, 1977).

Finally, we quantified the time investment to enumerate 10 replicates of 200 seeds manually and with the CountThings app. We recorded the time to lay out the seeds, count them with a non-custom template (including the use of the CountThings adjustment tool to increase accuracy), and count them with the custom Sagebrush Seeds template (without using the adjustment tool). We used R 3.6.0 for data analysis (R Development Core Team 2019).

Our samples ranged in size from 7–531 seeds, with a mean of 176 seeds. Although the regression models were significant for each template ($p < 0.005$), the existing template models only explained 20–25% of the variability in the actual number of seeds in the photograph and the slopes of the model were not close to 1 (Table 1). In contrast, the custom Sagebrush Seeds template explained 83% of the variability in the actual number of seeds in the photograph, and when the model was forced through the origin, the explanatory power increased to 95% ($p < 0.0005$, Table 1). Because the slope of the relationship was different than 1 (95% confidence interval ranged from 0.81 to 0.93), the best model underestimated the number of seeds in larger samples.

We found that laying out the seeds on a piece of paper was the most time-intensive aspect of counting seeds; requiring a mean time investment of 576 sec (Table 2). However, this step is necessary regardless of whether the CountThings app is used or the seeds are manually counted. Using a non-custom template followed by the CountThings adjustment tool to increase accuracy took almost half the time that it took to count the seeds manually (66 versus 119 sec, respectively), and the custom Sagebrush Seeds template, which did not require the use of the adjustment tool, took just 13 seconds (Table 2).

Our research indicates that CountThings may be an effective method to quickly and accurately enumerate small, variably sized native seeds for restoration projects when a custom template is developed. For 200 seed replicates, using the custom CountThings template for sagebrush seeds took 10% of the time it took to manually count the same seeds. This difference could lead to significant savings in time (and money) over the course of a project where large quantities of seed need to be counted.

There are several factors to consider when using CountThings. To create a custom CountThings template, you must purchase a license. While the cost of the purchase would likely be offset by the time saved using a custom template, this is certainly a consideration in adopting the technology. It is also important to consider photo quality when using the app. For example, several of our replicates of 200 seeds were inaccurately estimated by the Sagebrush Seeds template (data not shown). This was likely due to low photo quality of some of the replicates. For most accurate results, seeds should be cleaned of debris, well-spaced on the paper, and the photograph should not be blurry. Cameras on modern smartphones and tablets as well as standalone digital cameras are adequate for photos if taken in well-lit conditions with spacing among seeds (Figure 1). The app adjustment tool might allow users to use a non-custom template for their project, however using the tool increases sampling time, which may negate any time savings.

Despite minor challenges, we have found CountThings to be a useful technology because of its accuracy, ease

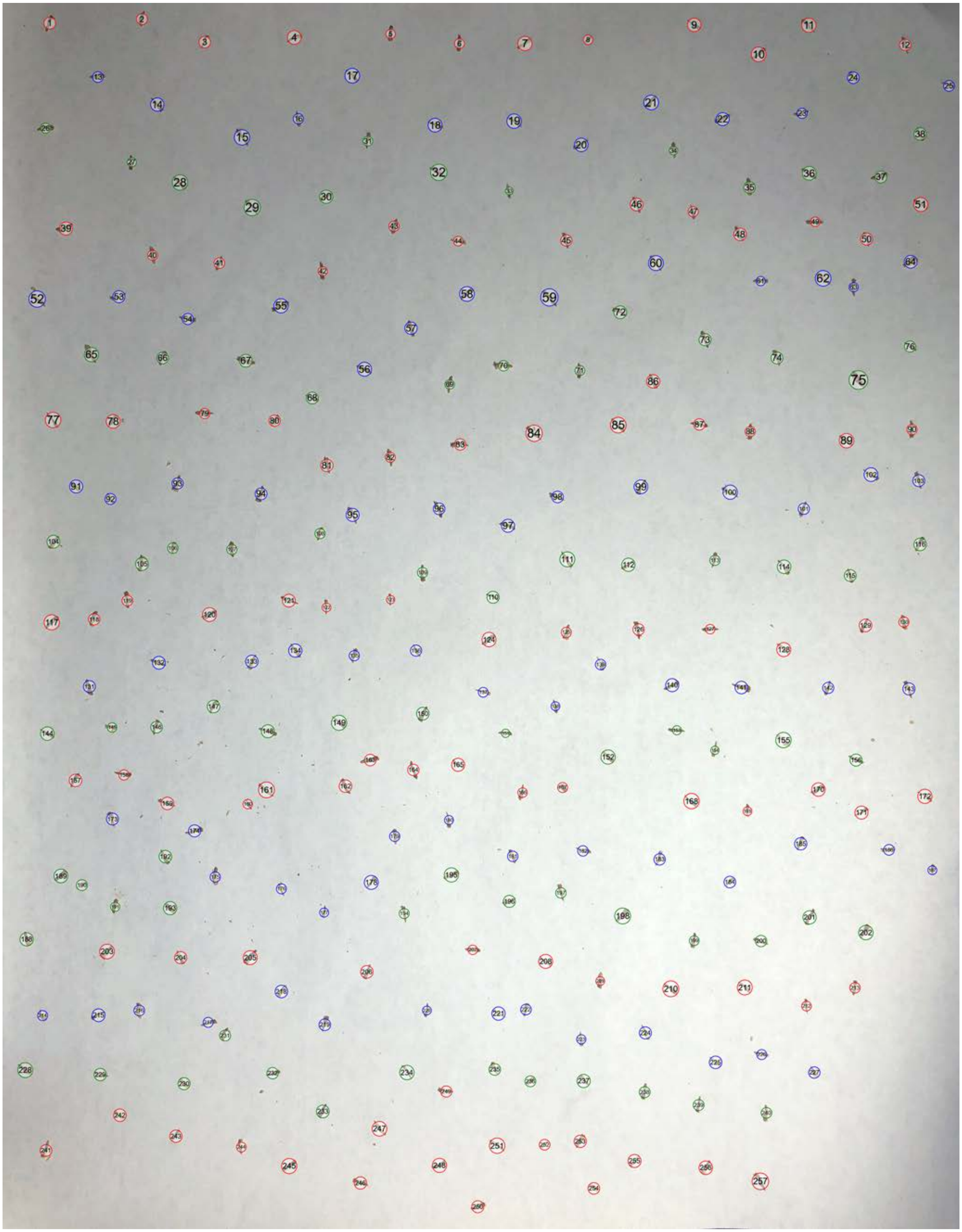

Figure 1. Photograph of the Sagebrush Seeds template applied to a photograph of sagebrush seeds spread across white paper. Each seed is circled and enumerated by the app. Count Things estimated 257 sagebrush seeds in this photograph and the actual number of seeds was also 257.

Table 1. Model results for each CountThings template tested. * Signifies models or parameters with $p < 0.05$, ** signifies models or parameters with $p < 0.005$, and *** signifies models or parameters with $p < 0.0005$.

Template Name	Model	R^2
Baby Tilapia Fingerlings	y = 6.18 + 0.50x**	0.21**
Cattle	y = 28.47* + 0.24x***	0.25***
Potato Cyst Nematodes	y = 60.17 + 1.56x**	0.20**
Sagebrush Seeds	y = 7.90 + 0.84x***	0.83***
Sagebrush Seeds (forced intercept)	y = 0.87x***	0.95***

of use, and transportable software. Unlike other digital imaging programs, CountThings can be used on any smart phone, laptop, personal computer, or tablet without any additional software. CountThings can allow for a streamlined seed counting process, and saved results to help track restoration success. We recommend the software for a variety of applications, including academic research, native plant nurseries, and small nonprofits, due to the variety of price options and subscription lengths. A monthly or year-long license would be cost efficient for a group counting very large quantities of seeds, while organizations counting fewer seeds could use the free trial or purchase a one-month license.

The Sagebrush Seeds template could successfully be used for other plant species with small and similarly shaped seeds, which would eliminate the need for a subscription when counting a smaller number of seeds that could be counted within a week trial. However, seed shape will affect the accuracy of counting. For example: small, round seeds might not be as accurately estimated with the template as small, elongated seeds that are similar in shape to sagebrush seeds. Overall, based on its success counting small sagebrush seeds, we believe the app has great potential to rapidly enumerate a variety of native seeds for use in the field of ecological restoration.

Table 2. Time investment for seed layout, manual seed counting, non-custom template seed estimate including manual adjustment time, and custom template seed estimate (no manual adjustment needed). Values in table represent time investment (mean and standard error) for 200 seeds (n = 10).

Activity	Time Investment (s)
Seed Layout	576 (51)
Manual Count	119 (34)
Non-Custom Template with adjustments	66 (7)
Custom Template	13 (6)

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Author Contributions

Samantha Kelly and Cessair McKinney contributed equally to the development of this research and manuscript.

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