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Evaluation of Forestry Component Survival in Plots of the Program "*Sembrando Vida*" (Sowing Life) Using Drones

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Abstract: Reforestation is one of the main actions undertaken to mitigate the effects of climate change. In Mexico, the Federal Government program "*Sembrando Vida*" (Sowing Life) is currently the most important reforestation effort. It aims to recoup forest cover and achieve food self-sufficiency through the establishment of agroforestry systems. The evaluation of tree survival in reforested areas helps to identify achievements and failures, as well as aspects of the program that require improvement. However, given the magnitude of this program, evaluation using traditional methodologies is labor-intensive and costly. In this context, drones equipped with high-resolution cameras are a promising tool. The objective of this study was to evaluate the feasibility of using drones to monitor tree survival in reforested areas. This study was conducted in 12 randomly chosen plots, benefited by the "*Sembrando Vida*" program, located on the Purépecha Plateau in the state of Michoacán, in central–western Mexico. Field surveys with GPS were conducted to record the total number of live and dead forest-tree seedlings. Simultaneously, high-resolution images were captured using a DJI Phantom 4 Pro drone equipped with an RGB camera for subsequent visual interpretation in a geographic information system to determine the status of each seedling and calculate the rates of survival. ANOVA was performed to compare the survival calculated using the drone images compared to that recorded in the field. No significant difference was found between survival estimated using the drone and that recorded directly in the field in any of the study plots, although the drone overestimated survival by an average of 6%, mostly due to the presence of dead seedlings that had already lost their foliage and were thus missed when scoring the RGB image. It is therefore concluded that the estimation of survival using drones is a reliable method. For future research, it is recommended to evaluate machine-learning algorithms in terms of detecting both living and dead trees in reforested sites. It is also recommended to use multispectral thermal cameras and LiDAR technology to broaden the knowledge of the different levels of vigor/stress present in the vegetation.

Keywords: Purépecha Plateau; reforestation programs; *Sembrando Vida*; Sowing Life; unmanned aerial vehicles

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1. Introduction

The program "*Sembrando Vida*" (Sowing Life) constitutes one of the greatest efforts of reforestation undertaken by the current Mexican government, due to its enormous national coverage (approximately 450,000 beneficiaries in 2021) and huge level of investment (approximately USD 1780 million per year) [1]. The program is directed toward reducing social inequality, strengthening the social fabric, achieving food security [2], recovering ecosystems in sites inhabited by the most vulnerable social strata [3], and restoring forest and agroforest coverage in degraded sites, which could lead to economic income and environmental services (water and carbon capture and biodiversity conservation) [4]. The program consists of providing a monthly subsidy and technical advice to each beneficiary, such that they can establish and productively maintain a plot of 2.5 hectares in which traditional crops (such as local varieties of maize) are interspersed with fruit and/or forestry tree species [5]. In most of the beneficiary plots in central Mexico, species of the genus *Pinus*, including *Pinus pseudostrobus* Lindl., *Pinus devoniana* Lindley, and *Pinus greggii* Englem., among others, are cultivated [4].

However, in our opinion, since the forestry component of *Sembrando Vida* is operated by the new Mexican government department known as the "*Secretaría del Bienestar*" (Ministry of Welfare) and not by the Mexican National Forestry Commission (CONAFOR, its acronym in Spanish), important technical aspects that could improve plant quality, survival, and the growth of reforestations have been left aside, and it seems that the expected impacts of climate change, which are and will become progressively more severe, are being completely ignored [6–9]. Therefore, one of the greatest challenges faced by federal programs that support reforestation has been to maintain a level of survival equal to or higher than that established by some national organizations, such as CONAFOR, which usually requires a minimum survival rate of 70% as part of the rules of operation of its support programs [10]. In past six-year presidential terms, annual survival percentages per state were between 30 and 53%, with a national average of 43% [11].

On a global scale, reforestation programs in developing countries are considered an important means of climate change mitigation and adaptation; they are also necessary to preserve the livelihoods of rural communities and the ecosystem services provided by the forests [12]. However, despite substantial expenditure on reforestation programs, there is little information indicating the success of reforestation projects in achieving ecological or socioeconomic benefits [13].

In this context, it is important to monitor the survival of reforested areas and to communicate the experiences found in different types of ecosystems [14]. This procedure consists of carrying out consecutive and periodic evaluations of the quantitative and qualitative aspects of the newly planted trees. For example, Prieto-Ruiz et al. [15] evaluated the survival rate of the reforestations of *Pinus cooperi* and *Pinus engelmannii* and the effect of seedling morphological conditions in the state of Durango, Mexico. On the other hand, Gallardo-Salazar et al. [16] evaluated seedling quality attributes of the *Abies religiosa* from two different provenances in central Mexico and its subsequent evaluation of survival rate and growth increments in the reforestation site. In this manner, it is possible to determine the temporal and spatial dynamics of the plantation through measuring parameters such as the number of living individuals or their state of vigor, as well as the technical circumstances that were not considered at the beginning of the plantation, in order to implement measures of prevention, protection, and maintenance [17].

Assessments can be carried out through sampling or censuses, involving reforestation evaluators who often walk long distances through the plots with a handheld GPS receiver and count (one by one) the number of alive and dead seedlings (binary response, 1 = alive, 0 = dead), this way they are able to calculate the survival rate [17]. However, due to the large amount of time and resources required, and even the conditions of insecurity in the field such as those present in some regions of Mexico, it is advisable to implement state-of-the-art technology to monitor reforestation efforts [18,19]. Unmanned aerial vehicles, commonly known as drones [20], seem to be a promising option for generating detailed aerial information in a more autonomous, economical, and timely manner in forest areas [21]. Although satellite images can be used to monitor reforestation programs on a regional scale [22], drones have several advantages, such as spatial and temporal resolution (0.5 cm per pixel), which is essential when the seedlings are small, and their location with centimeter-level precision is needed to generate high-quality information [23]. This could make it possible to evaluate the survival of seedlings in small plots, such as those of the *Sembrando Vida* program (2.5 hectares), which were recently reforested with seedlings of an average crown diameter of only about 15 cm.

We therefore consider it of utmost importance to develop an innovative methodology for the assessment of the forest component survival of the *Sembrando Vida* program using low-cost civilian-use drones [24] that are accessible to forest communities [25]. This could eventually allow for the rapid and large-scale assessment of the survival of the seedlings established in *Sembrando Vida* plots, possibly reducing the costs in effort and time compared to traditional field-assessment techniques [26,27].

The use of drones of these characteristics could be carried out by personnel or entities independent of the Program, giving integrity and social credibility to the results of such evaluations, especially considering the large economic investment that this program represents and the context of an environment of political polarization such as the one currently experienced in Mexico.

The present study addressed only reforestations of the *Sembrando Vida* program using forest species of the genus *Pinus*. The evaluation was conducted in the Meseta Purépecha of the state of Michoacán in central-western Mexico because it is a priority area for its indigenous population, which is economically disadvantaged but with a high degree of community organization in many of its communities (such as Cherán) [28,29].

The objective of the present study was to prove that it is possible, using low-cost civilian drones, to determine the survival of the forestry component of the Sembrando Vida program in a statistically reliable manner. We also sought to answer the following question: is the resolution of the images generated by these drones sufficient to distinguish between dead and alive individual reforestation seedlings in plots of beneficiaries of this program in the Meseta Purépecha, state of Michoacán, Mexico?

2. Materials and Methods

2.1. Study Area

The evaluation of the forestry component of *Sembrando Vida* focused on beneficiary plots of the program in the Meseta Purépecha located in Michoacán state since it is a priority indigenous region with multiple social and environmental problems. The Meseta Purépecha is located in the west–central portion of the state of Michoacán (Figure 1). It is an area bordered by mountain ranges that form part of the Transversal Volcanic System, with extensive pine and oak forests that give rise to a temperate, humid-to-sub-humid climate, and it contains mainly andosolic soils [30]. Due to its volcanic-ash origin, its agriculture is limited to certain varieties of locally developed crops. Most families in the region are mainly dedicated to the production of rainfed maize associated with the fattening of some animals [31]. This crop is planted primarily under the social property regime [29].

2.2. Selection of Evaluated Plots

The evaluations were conducted in 12 plots of beneficiaries of the *Sembrando Vida* program. The plots were chosen at random from those under the responsibility of the program's technicians, who were also chosen at random. The only additional criterion considered prior to choosing the 12 plots was that they were located in regions with adequate security conditions to safely carry out the fieldwork, which was determined through interviews with the regional coordinators and the state coordinator of the program.

2.3. Census of the Survival of the Forestry Component

Once the plots to be evaluated were selected, field visits were conducted together with the technicians in charge of the plots. Using a handheld GPS (Garmin eTrex 20x, Garmin, Olathe, KS, USA), the location and total number of live and dead trees were recorded while walking over each plot. A plant was considered to be alive when green or partially green foliage (in the second case with yellowish parts of the foliage, indicating loss of vigor but still alive) was present. A plant was considered dead when the foliage was completely brown and dry, or had been shed, but the stem or at least a fragment of the stem was still present. Table 1 describes the location of the 12 plots chosen. These plots had all been reforested in 2021. The species that were used in the forestry component were, in order of importance, *Pinus pseudostrobus* Lindl. (36%), *Pinus greggii* Englem. (22%), *Pinus leiophylla* Schl. & Cham (17%), *Pinus devoniana* Lindl. (14%), and *Pinus ayacahuite* Ehren. (11%).

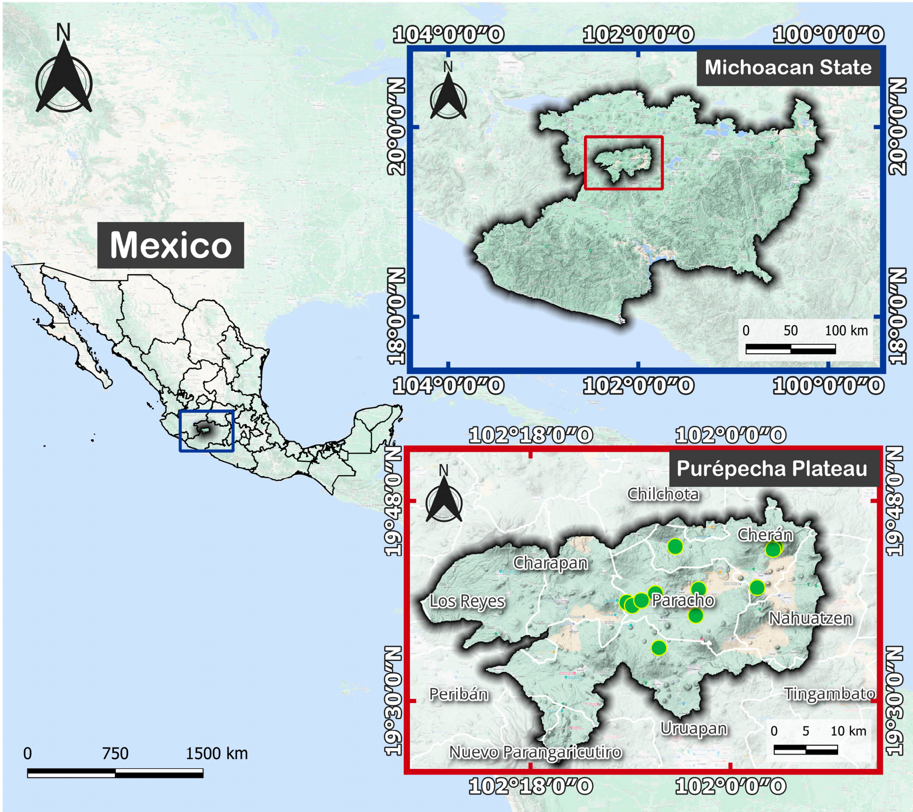

Figure 1. Location and distribution of the 12 selected beneficiary plots (green dots) of the *Sembrando Vida* program, located in the Meseta Purépecha in the state of Michoacán, central–western Mexico.

Table 1. Location and forest species used in the 12 randomly selected plots that had been reforested in 2021.

Plot	Municipality	Coordinates
1	Cherán	19.7321° N, 102.08288° W
2	Charapan	19.647839° N, 102.155674° W
3	Paracho	19.63818° N, 102.14781° W
4	Paracho	19.65086° N, 102.13361° W
5	Paracho	19.66143° N, 102.11265° W
6	Cherán	19.66956° N, 101.95998° W
7	Cherán	19.731087° N, 101.934684° W
8	Cherán	19.731135° N, 101.932986° W
9	Cherán	19.72743° N, 101.936124° W
10	Paracho	19.628509° N, 102.052013° W
11	Uruapan	19.579508° N, 102.10737° W
12	Paracho	19.6673° N, 102.047824° W

2.4. Estimation of Survival of the Forestry Component Using Drones

2.4.1. Unmanned Aerial Vehicle Used

The drone used was a Dà-Jiāng Innovations (DJI) quadcopter, model Phantom 4 Pro (P4P) (DJI, Shenzhen, Guangdong, China) (Figure 2). It has a 20 MP camera with a 1-inch sensor, focal length of 24 mm, and RGB sensors (Red, Green, and Blue, i.e., visible light spectrum). The P4P operates under the principle of direct on-board georeferencing, and is equipped with GPS that geotags each acquired image with coordinates. This indicates that all acquired images were directly georeferenced using the GPS capability during the flight mission [32].

Figure 2. Unmanned aerial vehicle, model Phantom 4 Pro, used to acquire images.

2.4.2. Planning and Execution of Flight Missions

The flight missions were executed on 7, 9, and 25 May 2022, which coincides with the dry and warm season in this region of the country. Thus the appropriate characteristics were present to evaluate the reforestations while avoiding interference and confusion in the images by the presence of herbaceous or shrubby vegetation, which is generally dry at that time of the year. Preliminarily, the polygons of the 12 plots chosen to be evaluated were provided (*.kml format) by the technicians in charge of the program. In this way it was possible to configure the flight missions and ensure that the area to be evaluated with the drone coincided in full with the entire plots in the field. The flight plan for automatic image acquisition was programmed with the Pix4D Capture application [33] to fly the P4P. The flight parameters were a frontal and interline overlap of 80%, and flight altitude of 16 m above ground level (AGL) with a camera angle of 90°. It is important to mention that some pilot test flights with different heights of flight were made previously. We concluded that 16 m was the minimum flight height to obtain an optimum level of detail to evaluate the condition of small seedlings (averaging a height of 20 to 30 cm and a crown diameter approximately of 15 cm). The flights were conducted under sunny conditions and clear sky (no clouds) to avoid shadow interference, with wind speeds below 5 km/h. The average flight time per plot was 21 min, while with the traditional method, the average time necessary per plot was 56 min.

2.4.3. Photogrammetric Process and Estimation of the Survival of Reforested Areas

From the RGB images captured by the P4P, photogrammetric and computer vision procedures were applied using the free and open-source software OpenDroneMap 3.0 (ODM) [34]. This software implements modern Structure from Motion (SfM) and Multi-View Stereo (MVS) algorithms to estimate 3D models from 2D image sequences with a high percentage of overlap [35] that are used to build an orthomosaic [36,37]. This process generated the high-resolution RGB orthomosaics of the 12 beneficiary plots of the *Sembrando Vida* program.

Subsequently, to perform the visual assessment of survival, the generated orthomosaics were integrated into the free and open source geographic information system software, QGIS 3.28 [38], to detect the status of individuals grouped into live or dead categories and thus calculate survival. Thus, Figure 3 shows the contrast between alive and dead seedlings from the on-the-ground field view (Figure 3a,b, respectively) and the orthogonal view of the orthomosaic generated with photogrammetry displayed in QGIS (Figure 3c,d).

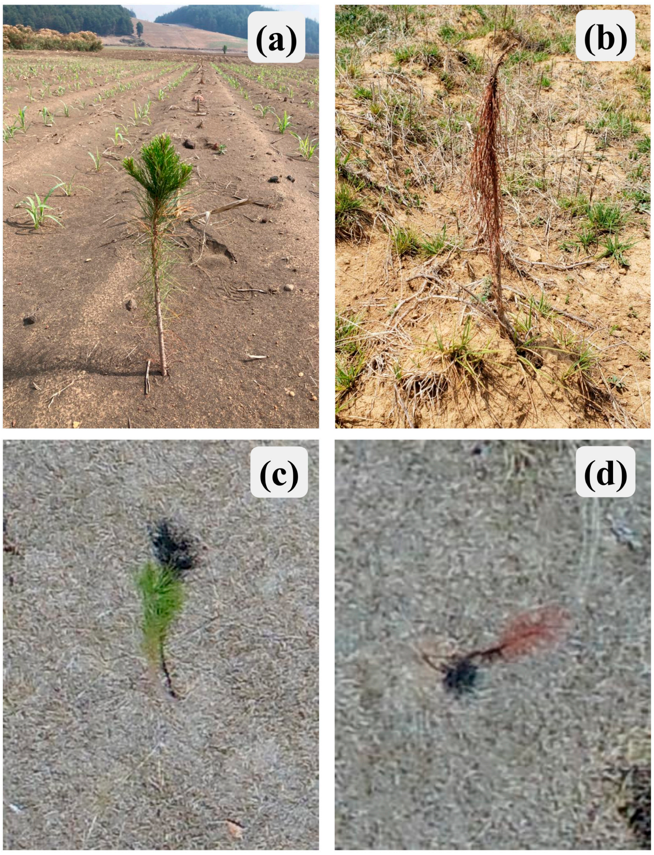

Figure 3. Alive and dead seedlings, from the field view ((**a**,**b**), respectively) and the orthogonal view of the orthomosaic generated using drones (**c**,**d**).

Once the alive and dead seedlings were counted, the survival rate was estimated, which describes the number of alive seedlings as a function of the total number of seedlings present (either alive or dead). This is expressed with Equation (1).

$$Survirval\ rate = \frac{a}{(a+b)} \times 100 \tag{1}$$

where a is the number of alive individuals, b is the number of dead individuals, and (a + b) is the total number of seedlings assumed to be established.

2.5. Statistical Analysis

To detect possible differences in the survival results of the forest component calculated with drones with respect to those in the census recorded in the field, an "overall" analysis of variance (ANOVA) was performed, comparing the 12 plots as a whole, using the statistical software R 4.1.2 [39]. In addition, ANOVA was performed for each of the plots separately, comparing the two evaluation methods (field census vs. drone). For this second analysis, to have variance within each evaluated plot, the plots were divided into blocks, which were shaped to fit the highly variable planting arrangement of the forest component. Thus, the plots were divided, in most cases, into at least 10 linear transects (furrows). In some cases, the transects were distributed in the periphery of the plot since the trees had been deliberately planted in that way so that they would form windbreaks in the future. In a few cases, the blocks were approximated as rectangular (sometimes irregular due to the topographic conditions of the site, such as rock outcrops) to capture the variation within the plot when planted in groups and not in lines.

3. Results

An average of 500 photographs per plot were captured with the RGB sensor of the P4P to generate the 12 corresponding orthomosaics. Figure 4 shows the spatial distribution of the 12 analyzed plots (upper part) and three examples of orthomosaics generated by the photogrammetric process for the beneficiary plots (lower part). On average, the resulting orthomosaics presented with a 0.5 cm spatial resolution (GSD, ground sample distance); i.e., each pixel in the digital image represents 0.5 cm projected on the ground.

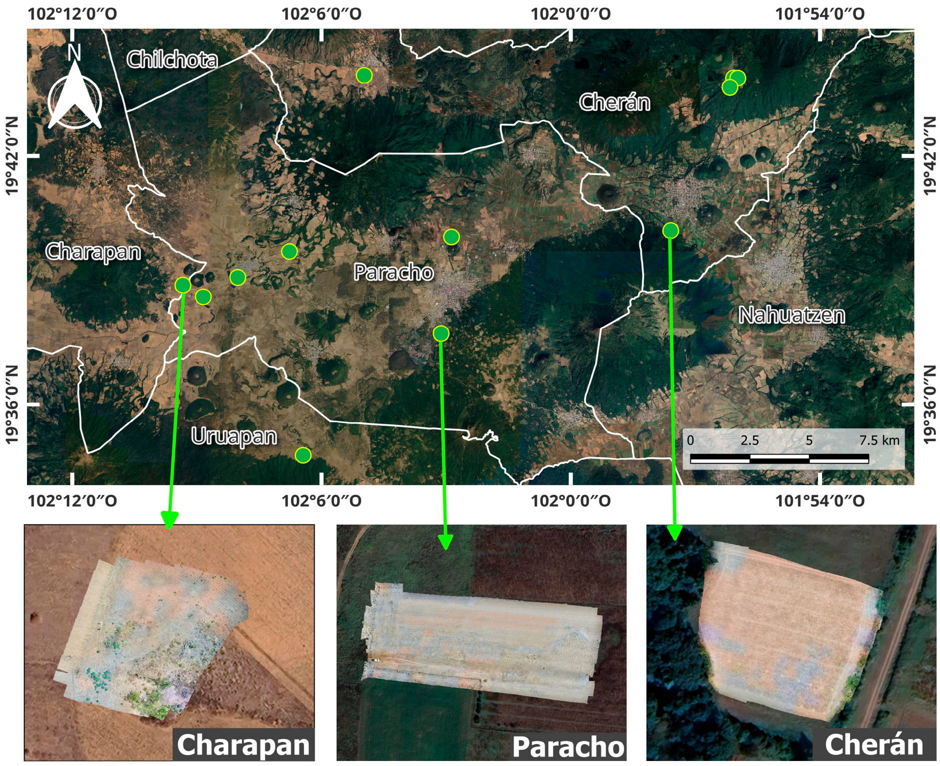

Figure 4. Examples of the spatial distribution of the orthomosaics (green dots) generated by drone photogrammetry of the 12 beneficiary plots in the Meseta Purépecha region, state of Michoacán, Mexico. The white lines in the upper panel denote the municipal division. The name of each municipality is indicated.

Likewise, Figure 5 illustrates the process of the visual interpretation of live and dead trees within the QGIS from the orthomosaics generated. Similarly, the data captured with the GPS were loaded and classified as live or dead from the field surveys. Note the spatial offset of the trees recorded using the different methods, which is due to the precision of the single frequency GPS receivers, which can range from centimeters to a few meters of error in geolocation [40].

Subsequently, ANOVA was performed to analyze whether there was a difference between the estimation of survival of the forest component using drones and the census of survival in the field. The average survival in the 12 plots calculated with the field census was 60.9%. Although the drone overestimated survival by almost 6% (mean = 66.7), the ANOVA revealed that there was no statistically significant difference in mean survival values (p = 0.152) (Table 2). Figure 6 graphically represents Tukey's HSD test for multiple comparisons of survival means for each plot after performing ANOVA separately for each plot. This second ANOVA revealed no significant differences in any of the cases ($p > 0.05$).

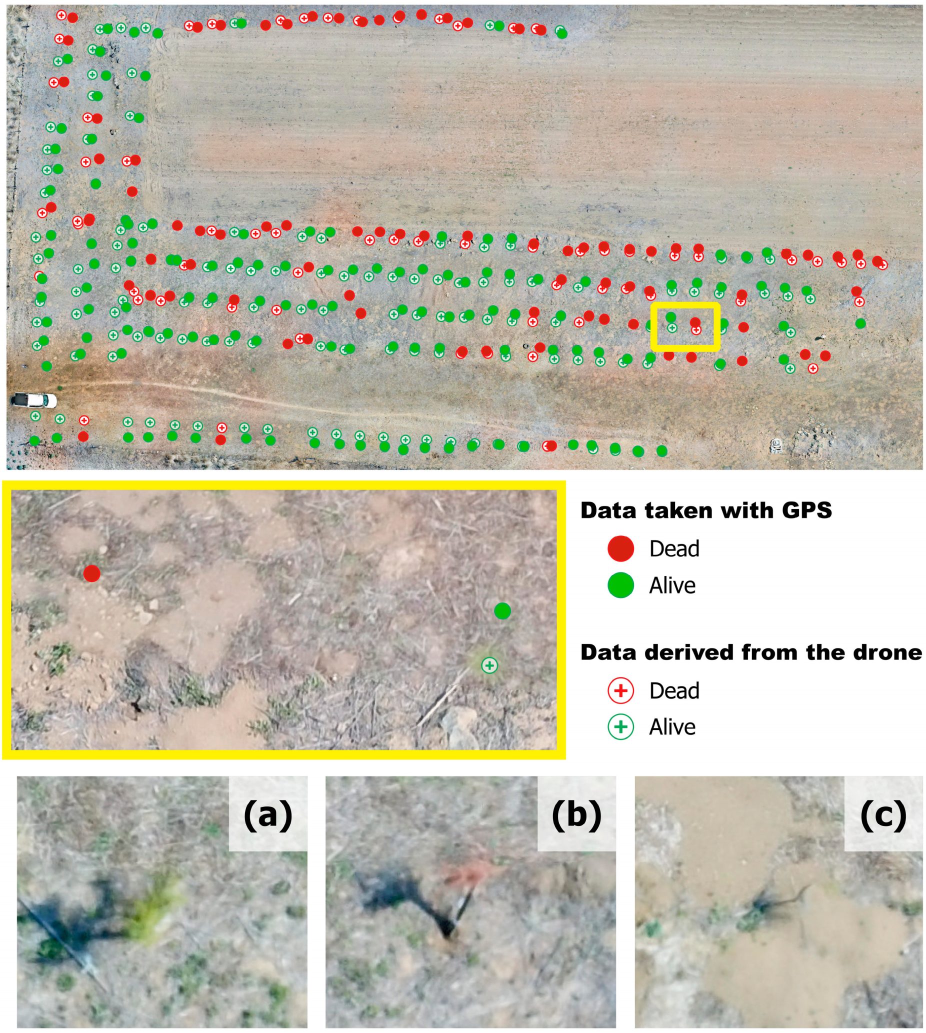

Figure 5. Comparison within the QGIS of forest component survival data collected in the field with GPS and those estimated using drones: (**a**) corresponds to a seedling identified as alive, (**b**) a seedling identified as dead, and (**c**) a possible error of omission since it was possible to corroborate the dead seedling in the field inspection while it was not possible to visualize the seedling with visual interpretation on screen.

Table 2. Results of the "overall" ANOVA between methods for calculating the survival of the forest component (field census vs. drone), analyzing the 12 evaluated plots as a whole.

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F	p
Method (Field or Drone)	1	1040	1039.7	2.074	0.152
Error	122	61143	501.2		
Total	123				

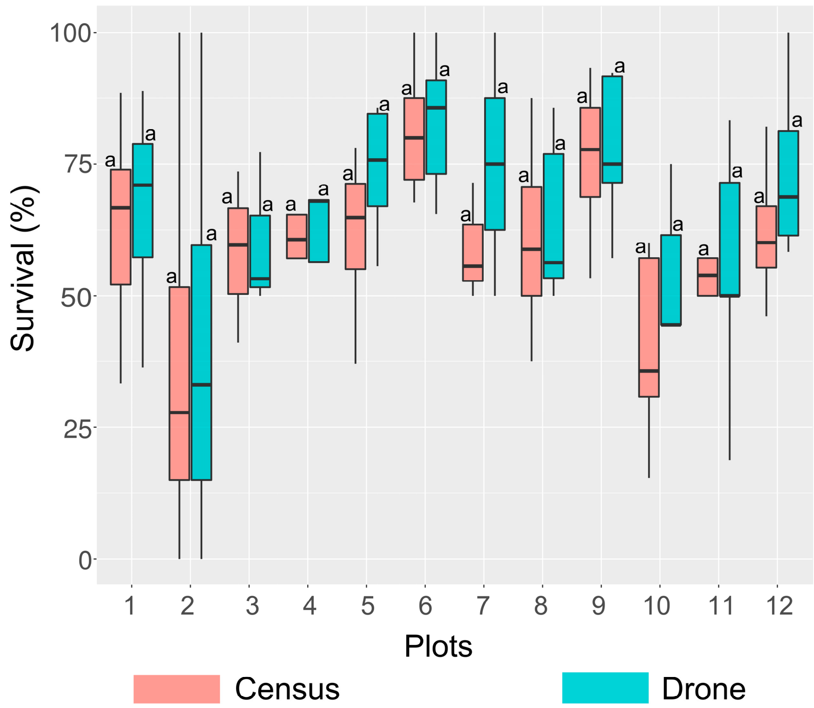

Figure 6. Box plot illustrating the survival estimated using drones and in the field census. The line across the box corresponds to the median, and the rectangle corresponds to the interquartile range. Boxes with the same letter do not differ significantly (multiple comparisons of means Tukey's post hoc test, $p \geq 0.05$).

4. Discussion

The present research focused on the development of a practical methodology to evaluate the survival of forest tree species seedlings in reforestation programs in a statistically reliable manner and using low-cost civilian drones. The main contribution was to prove that the estimation of seedling survival in reforested areas approximately one year after planting is statistically reliable, in the sense that it does not differ statistically from an estimation based on a field census (Figure 6). In addition, the drone-based assessment is much faster in terms of the time required to be in the field, which is a significant advantage in situations where field conditions are insecure. This advantage is increased in cases where a series of spatially contiguous reforested plots are evaluated since the drone flight can be planned to include several plots in the same flight.

We can postulate that the drone model, configuration of flight parameters, and photogrammetric processing, were adequate to generate high-resolution maps to distinguish between alive and dead small (about 15 cm of crown diameter) seedlings. Regarding the brand and type of drone used, we agree with Gallardo-Salazar et al. [41], who reported that flying DJI multirotor drones had advantages in versatility and maneuverability in complex forest ecosystems instead to other brands and fixed-wing drones. However, it would be desirable in the future to conduct a formal comparison among drones' brands and models.

It is important to highlight that, despite the complexity involved in managing an agroforestry crop and the technical aspects during the process, which apparently were not fully taken into account, i.e., seed origin, plant quality, planting season, and even mortality through the actions of gophers (aspects mentioned via personal communication by the technicians in charge of the program), the average survival rate was 60.9% (considering 100% to be the total number of live or dead plants present). This value is higher than that reported in past six-year periods for federal reforestation programs [11]. It is beyond the scope of this paper to analyze in detail the possible technical and socio-political causes involved in the survival of the program's plantations; however, it is expected that future studies will address these issues.

The main source of survival overestimation (6%) using drones was the limitation in visual interpretation of the orthomosaics in terms of detecting dead trees (Figure 5c), which could be detected with the field survey. These results agree with those of Feduck et al. [42], who developed a methodology using drones integrated with an RGB (visible light range) sensor to detect conifer seedlings in logging areas. The results of that study also suggest an underestimation of seedling density. Reis et al. [43] compared forest restoration monitoring methods with multispectral images captured with drones, concluding that the methods used were efficient for monitoring restoration areas, with an emphasis on large-scale projects, saving time, fieldwork, and invested resources. On the other hand, in the present study, the accuracy in detecting the number of live trees was over 90%. This has become important considering the recent boom in the use of drones and automated learning algorithms applied to agroforestry crops [44,45], especially for the design of maps for the replanting or replacement of dead plants [46,47].

In the present study, an average spatial resolution per plot of 0.5 cm was achieved, which allowed for the detection of the live and dead trees within the plots in most cases (Figure 5). This illustrates the considerable potential of drones for use in environmental monitoring [48,49], in particular for the study of forest resources [50], as they allow for a high level of spatial resolution at a relatively low cost compared to other remote sensing methods, such as manned flights or satellite imagery [51,52].

Although there are several platforms on the market to count or detect trees in plots for reforestation purposes (https://www.skylabglobal2.com/; accessed on 8 September 2023), to date, there are no known studies that are adapted to the particular conditions of the ecosystems and biodiversity of Mexico [41], so the present work is considered a useful contribution in the Mexican context. It is important to highlight that the present methodology is limited to plots with no dense forest canopy since this would prevent the detection of the lower strata and the counting of trees that have been recently planted for ecological restoration purposes.

For future research, and to increase the sophistication of the methodology described in this study, it is recommended to evaluate automated learning algorithms to detect live and dead trees in reforested sites, e.g., TensorFlow [53], Yolo [54], and PyTorch [55]. Moreover, where funding is available within the reforestation or restoration programs, it is recommended to explore the use of multispectral and thermal cameras, as well as LiDAR technology, to increase the knowledge on the different levels of vigor/stress and the development of trees planted for reforestation purposes.

5. Conclusions

The methodology developed in this study made it possible to calculate the survival of the forest component of the beneficiary plots of the *Sembrando Vida* program with statistical reliability. In this sense, the drone model, the configuration of flight parameters, and photogrammetric processing (with an emphasis on the use of free software) were adequate to generate high-resolution maps and to distinguish between live and dead small seedlings of forest-tree species. Although the methodology is limited to plots without a dense forest canopy, we identified that evaluation with a low-cost drone was faster in terms of the time required in the field, which can save time, fieldwork, and invested resources, with a special emphasis on the advantage this represents when there are conditions of insecurity in the field, such as those that often occur in some regions of Mexico. Another advantage is the ability of the methodology to easily integrate with GIS technology and analysis software.

We also believe that the strategies to evaluate federal public policies should make a technological leap to ensure the correct execution of economic, human, and material resources. This highlights the importance of developing research such as the present study, which made it possible to evaluate the low-cost drone technology for civilian use that has recently gained momentum in Mexico in different disciplines. Moreover, drones may represent an opportunity and first approach for Mexican communities to obtain detailed aerial information in a more autonomous, economical, and timely manner for use in the near future, for example, in the monitoring and management of forest fires, pests, and diseases.

Finally, in order to improve the survival of forest species based on the results and what was observed in the field, it is suggested to conduct future research to identify the causes of seedling mortality, such as species and seed provenance selection, the quality of seedlings produced in the nursery, the timing of planting during the rainy season, soil moisture availability, the occurrence of extreme high or cold temperatures, and, very important in our particular studied region, mortality due to the actions of gophers.

Author Contributions: C.S.-R., J.L.G.-S. and V.O.-V. planned and designed the research; J.L.G.-S. and V.O.-V. led the writing of the manuscript; J.L.G.-S. and V.O.-V. conducted the statistical analyses; R.A.L.-C. and A.B.-G. provided important suggestions during the development of the project and the data discussion. All authors have read and agreed to the published version of the manuscript.

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Data Availability Statement: Data presented in this study are available upon request from the corresponding author.

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Conflicts of Interest: The authors declare no conflict of interest.

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