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TITLE

Testing the efficiency of structured and unstructured surveys for detecting a small population of Jack in the Pulpit (*Arisaema triphyllum*) plants

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ABSTRACT

Detecting inconspicuous species with low abundance is challenging, yet failure to detect these species can have important conservation implications. Few experimental studies have been conducted to assess how survey protocols affect plant species detectability. We tested the efficiency of structured (transect based) and unstructured (unplanned search) surveys for the detection of a small, simulated population of Jack in the Pulpit (*Arisaema triphyllum*) plants. We found no significant difference in the mean percentage of plants detected between survey types (27% structured, 31% unstructured , 95% CI = -0.23, Inf). However, unstructured surveys detected slightly more plants per unit time, while structured surveys covered a slightly larger portion of the study area. Participants located 33% of plants across all 18 surveys. The probability of finding all plants in a single survey was very low (7.59×10^{-4} to 8.89%). To ensure a 95% probability of detection of at least one plant in our study, a minimum of two to four surveys would be required. These results suggest that for population estimation or presence / absence surveys, particularly for species of conservation concern with low abundance or invasive species at the early stages of invasion, a single survey might not be enough.

Key words: detectability, monitoring, rarity, endangered species, methods

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RÉSUMÉ

La détection d'espèces peu visibles et peu abondantes représente un défi majeur, mais l'incapacité à les repérer peut avoir des conséquences importantes pour leur conservation. Peu d'études expérimentales ont évalué l'impact du choix de protocole sur la détectabilité des espèces végétales. Notre étude compare l'efficacité des relevés structurés (par transects) et non structurés (prospection libre) pour la détection d'une petite population simulée d'arisème petit-prêcheur (*Arisaema triphyllum*). Nous n'avons pas observé de différence significative dans le pourcentage moyen de plantes détectées entre les deux méthodes (27% structuré, 31% non structuré, 95% CI = -0.23, Inf). Néanmoins, les relevés non structurés ont détecté légèrement plus de plantes par unité de temps, tandis que les relevés structurés ont couvert une surface d'étude un peu plus grande. Les participants ont correctement identifié 33% des plantes sur l'ensemble des 18 relevés. La probabilité de trouver toutes les plantes en un seul passage était très faible (7.59×10^{-4} to 8.89%). Pour assurer une détection à 95% d'au moins un individu dans nos placettes, nous avons estimé qu'un minimum de deux à quatre relevés serait nécessaire. Cela suggère que pour les inventaires de population ou présence/absence, notamment pour les espèces à enjeu de conservation peu abondantes ou les espèces exotiques envahissantes en phase précoce d'invasion, un unique relevé pourrait s'avérer insuffisant.

Mots-clés: détectabilité, suivi, rareté, espèces menacées, méthodes

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INTRODUCTION

Detecting inconspicuous species with low abundance is challenging (Dennett and Nielsen 2019; Chen et al., 2013), yet failure to detect these species can have important conservation implications. If the species is endangered and we fail to detect it, we may not be able to adequately protect it (Bennett et al. 2024). If the species is an invasive at the early stages of invasion, we may not be able to prevent its spread (Hauser & McCarthy, 2009).

Numerous experimental studies have been conducted to assess factors that affect the detectability of plant species, such as differences due to morphology, survey effort and patch size (Chen et al., 2009); species abundance and arrangement (Dennett et al., 2018); life stage (Kéry and Gregg 2003); surveyor experience, and background vegetation characteristics (Hauser et al., 2022). Assessing the detectability of rare plants is very important, because many plants are threatened with extinction, and many invasive plants are initially rare when they colonize new areas.

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Yet, few studies have assessed how survey protocols affect plant species detectability, with notable exceptions being Huebner (2007) and Perret et al., (2023). Huebner assessed the ability of four sampling methods (i.e. timed meanders, evenly spaced plots, stratified random plots, and modified Whittaker plots) to detect and monitor understory invasive plant species in hemlock and red oak forests. Huebner found that timed meanders detected the greatest number of invasive species, but could not accurately document species abundance. Perret et al. assessed the efficacy of three methods (i.e. 30 second counts, unlimited time counts, and grid counts) to census plants in 1 x 1 m quadrats with varying degrees of conspicuousness (i.e. size and flower colour). Perret et

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al. found that detection probability increased with survey time and that grid counts achieved the highest detectability rates. To our knowledge, no experimental studies of this kind have been conducted to investigate different survey protocols to detect inconspicuous species with low abundance.

The objective of our study is to test the efficiency of structured and unstructured surveys for the detection of a small, simulated population of Jack in the Pulpit (*Arisaema triphyllum*) plants in vegetative state. We defined structured surveys as a systematic data collection protocol in which surveyors follow pre-planned transects covering the entire study area. We defined unstructured surveys as a flexible data collection protocol in which surveyors explore the study area at their discretion, until they feel they have adequately searched it.

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Structured surveys have various advantages over unstructured surveys. They allow for easier replication of the survey protocols over time or across sites, and their comprehensive coverage of the study area reduces the risk of surveyors inadvertently concentrating efforts in easily accessible areas (Alberta Native Plant Council, 2012; Henderson, 2009). Conversely, unstructured surveys can be more time efficient, and their flexible sampling nature can allow surveyors to examine the same area in multiple directions or focus on areas where the species is likely to be present but might be more difficult to detect, potentially increasing the chances of finding the target species (British Columbia Ministry of Environment and Climate Change Strategy, 2018). Comparing the efficiency of these two survey protocols could allow us to customize study designs for detecting inconspicuous species with low abundances and inform survey guidelines for rare and invasive species in similar contexts.

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Because of their thorough nature, we predicted that structured surveys would detect a greater percentage of plants than unstructured surveys. This is because by covering the entire study area, we expected that structured surveys would result in a greater probability of encountering and thus detecting the plants than unstructured surveys. However, we anticipated that unstructured surveys would be faster than structured surveys because they might only survey a portion of the study area and therefore detect a greater percentage of plants per time unit. This is because in unstructured surveys surveyors might inadvertently miss surveying some areas or they might navigate the study area in a more efficient way, by spending more time in areas where the plant might be difficult to detect.

In addition to testing the efficiency of structured and unstructured surveys, we also examined the general efficiency of our surveys for detecting our study species. Specifically, we calculated the probability that all plants were found in a single survey, and the expected number of surveys that would be needed to detect at least one plant in our study plots with 95% confidence. We decided to perform these additional calculations because pre-disturbance surveys conducted to assess the impacts of proposed development often consist of a single survey, which might not yield accurate information. We chose a 95% confidence threshold following the guidelines recommended for Ontario species at risk surveys, which state that search effort needs to be enough to provide at least 95% confidence in the survey results (Ontario Ministry of the Environment, Conservation and Parks, accessed April 2025).

METHODS

Jack in the Pulpit (*Arisaema triphyllum*)

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Jack in the Pulpit (*Arisaeama triphyllum*) (Figure 1) is a tuberous geophyte which can be found in the Central and Eastern parts of Canada and the US (Thompson, 2023). Although this species is apparently secure, it is facing increasing threats from invasive alien species, such as garlic mustard (*Alliaria petiolata*) and common buckthorn (*Rhamnus cathartica*) (Nature Conservancy of Canada, accessed March 2023). Detailed information about the threats that Jack in the Pulpit faces is still missing (NatureServe, accessed April 2025) and to our knowledge, there are no specific management actions targeted towards this species. In Manitoba (Canada), this species is listed as rare (S1S2 status rank) probably due to its naturally low number of occurrences, and it is recommended to monitor population numbers in areas of extant and historical occurrences in the province (Manitoba Conservation Data Center, accessed March 2023). However, monitoring the population numbers of this species can be challenging for several reasons. First, the plant takes a long time to germinate, and it grows slowly, therefore it remains inconspicuous for a long part of its life-cycle. And second, the seedlings of this plant can be easily confused with those of other species, such as large white trillium (*Trillium grandiflorum*) (Figure 1). Given the difficulty in detecting and identifying Jack in the Pulpit, particularly at its earliest life stages, we decided to use this species as a case study for other inconspicuous species. For example, when the endangered American ginseng (*Panax quinquefolius*) is in vegetative state some iNaturalist users confuse this species with Jack in the Pulpit, or Wild sarsaparilla (*Aralia nudicaulis*), which live in similar habitats.

Experimental design

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Our study was conducted at High Lonesome Nature Reserve in Pakenham, Ontario (Canada). This reserve is composed of regenerating forest, meadows, and wetlands. We created two survey plots of 100 x 100 m in the regenerating forest portion of the reserve, where we hadn't observed any naturally occurring Jack in the Pulpit plants. We chose a plot size of 100 x 100 m because plots in pre-development surveys or environmental impact assessments can be of a similar size, and other detectability experiments such as Garrard et al. (2015) have also used 1 ha plots. The vegetation of the survey plots was relatively homogeneous and was mainly composed of sugar maple (*Acer saccharum*), red oak (*Quercus rubra*), and white pine (*Pinus strobus*), with an understory of common juniper (*Juniperus communis*) and large white trillium (*Trillium grandiflorum*).

We planted eight Jack in the Pulpit plants across the survey plots, five in plot A and three in plot B (Figure 2). We chose to vary the number of plants in each plot to avoid influencing the surveyors' behavior upon noticing identical plant counts in each plot. We used the 'random points inside polygons' function in ArcGIS Desktop 10.5. (Esri Inc. 2016) to place the plants randomly within the plots, ensuring that each plant was at least 15 meters away from any other. This distance was chosen to differentiate which plants were detected in each survey, even if the reported coordinates had a GPS error of a few meters. All Jack in the Pulpit plants came from the same nursery, were in vegetative state, and were approximately four years old. Plants were carefully planted to minimize soil disturbance, a few days before the first survey.

The surveys took place from June 8 to July 10, 2023. We randomly allocated the plot and survey technique to the nine participating surveyors. Surveyors were contacted by word of mouth, and had varying levels of botanical expertise. We allowed only one surveyor at

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a time in each plot. We did not inform the surveyors about the specific number of plants in each plot; we only told them that there was a low number of Jack in the Pulpit plants, as we were mimicking a low abundance scenario. Each surveyor was provided with a scribe for safety reasons, since there were bears in the area. The scribes entered the detection information provided by the surveyors on the data spreadsheets, and always walked behind the surveyors to avoid causing distractions or unintentionally leading them to the plants. Scribes remained neutral throughout the surveys and all surveyors were accompanied by a scribe in all surveys. However, we acknowledge that surveyors knew they were being accompanied, and consequently they may have searched more meticulously. Surveyors recorded the GPS coordinates of the plants they found. Shortly after each survey, the project leader went back to the plots and confirmed the presence of all plants. If a plant was noted as missing, we replaced it with another one and did not consider the missing plant as a missed detection in the previous survey; this only happened twice. We also recorded the GPS tracks of the surveyors to calculate the percent area covered of the plot, by assuming that surveyors scanned five meters on either side of the track lines in both survey types (Table S1). We used 10 m wide buffer lines assuming that each surveyor's maximum field of view would be five meters to each side, following the recommendations outlined in Henderson (2009). This project was approved by Carleton University Ethics Research Board (CUREB-B application # 119463), all participants gave informed consent before participating in this study.

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Survey protocols

For the structured surveys we created a kml file dividing each plot in 10-meter-wide parallel transects. Surveyors uploaded the kml file to Google Earth on their phones and tried to stay in the middle of the transects, scanning the area five meters to their left and five meters to their right. Once surveyors had completed the ten transects, the survey terminated. For the unstructured surveys, surveyors explored the plots based on their previous expertise doing botanical surveys until they felt that they had adequately searched the plot.

Data analysis

To assess which variables were most relevant for species detection, we created generalized linear mixed effects models (GLMM) with a binomial distribution and logit link function using the glmmTMB package (Brooks et al., 2017) in R 4.3.1. (R Core Team., 2023). We started with a model in which detection was the response variable (0 – plant not detected, 1 – plant detected), survey type was the fixed effect, and plot ID, plant ID, and surveyor ID were random effects, with plant ID nested within plot ID. Although this model was the one that best aligned with our research question and data structure, it resulted in a singularity problem, and we decided to simplify the model by reducing the number of variables. We created a null model for comparison and selected the model with the lowest AICc value that did not result in a singularity problem as the best model. We tried adding other variables to the best model, such as percent area covered, total survey time, or plot order visit, but none of those models had lower AICc values (see Tables S2 and S3 for a description of variables and a list of models explored). We also performed a two-sample one-tailed t-test assuming equal variances to assess differences in mean detectability between survey types. This analysis was performed alongside the models to facilitate a clearer interpretation of any differences observed.

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To calculate percent detection per time unit (% detection / min), we used duration from survey start to finish in minutes, excluding any pauses the surveyors took (e.g., lunch or snack breaks). To examine the general efficiency of our surveys, we calculated the probability that all plants were found in a single survey using equation 1. Where p is the overall percent detection of Jack in the Pulpit plants, and k is the number of successfully detected plants (i.e., k=5 in plot A, k=3 in plot B, and k=8 for the mean probability of detecting all plants in the plots).

(1) p^k

In addition, we calculated the minimum number of surveys required to detect at least one plant with 95% confidence in our survey plots. For this, we used equation 2, where p is the overall percent detection of Jack in the Pulpit plants, k is the number of plants available for detection (i.e., k=5 in plot A, k=3 in plot B), and s is the number of surveys needed.

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(2) $\left((1-p)^k\right)^s \leq 0.05$ which can be re-written as: $s \geq \frac{ln\ 0.05}{k \cdot ln\ (1-p\ )}$

Finally, we calculated equations 1 and 2 substituting p with the detection probability estimates from the model with the lowest AICc value, along with their corresponding standard errors. We performed these calculations to assess how uncertainty in the detection probability estimates propagated to both the probability of finding all plants in a single survey and the number of surveys needed to detect at least one plant with 95% confidence in our survey plots.

RESULTS

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There were a total of 70 detection opportunities (9 surveyors x 8 plants - 2 missing plants). Of the 70 detection opportunities, there were only 23 (33%) detections. The number of detections in plot A was 9 for structured surveys and 10 for unstructured surveys. In plot B, the number of detections was 2 for both types of surveys. There was one false positive, in which a surveyor misidentified a large white trillium for a Jack in the Pulpit. There was one instance in which a surveyor recorded the same plant twice; we considered this as a single detection for data analysis. The mean survey time for structured surveys was 113 minutes (min. = 57, max. = 196, median = 116 minutes) and for unstructured surveys 95 minutes (min. = 55, max. = 150, median = 87 minutes). The mean area that surveyors covered per minute in structured surveys was approximately 70 m2/minute (min. = 46, max. = 96, median = 68 m2/minute) and for unstructured surveys was 69 m2/minute (min. = 30, max. = 108, median = 73 m2/minute). Surveyors detected between 12% and 50% of the total number of plants.

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The model with the lowest AICc value was the null model (AICc = 90.7). Mean detection probability in this model was 32.9% (95% CI = 22.9% - 44.6%). The GLMM with the lowest AICc value had survey type as a fixed effect and plot ID as a random effect (Table 1). Mean detection probability in this model was 28.3% in structured surveys (95% CI = 10.8% - 56.1%) and 29.3% in unstructured surveys (95% CI = 11.2% - 57.6%). This model had an AICc of 92.6, a conditional R2 of 0.109, and a marginal R2 of 0.000. In the model including survey type (AICc = 92.6), the p-value for survey type was 0.9, suggesting that there was no significant difference in the probability of detection between survey types. See Table S4 for exploration of model residuals.

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The two-sample one-tailed t-test comparing differences in mean percent detection per survey type showed a similar result. Mean percent detection was slightly lower in structured surveys (27%) than in unstructured surveys (31%) (Figure 3), but this difference was not significant (t = -0.35, p = 0.6, df = 16, 95% CI = -0.23, Inf). Mean percent detection per time unit was slightly higher in unstructured surveys (0.4% detections / min) than in structured surveys (0.2% detections / min), but this difference was not significant (two-sample t-test: t = -0.9, p = 0.2, df = 16, 95% CI = - Inf, 0.001). Mean percent area covered was higher in structured surveys (74%) than in unstructured surveys (62%) (two-sample t-test: t = 1.65, p = 0.06, df = 16, 95% CI = -0.67, Inf), but this difference was marginally significant (see Table S1). Although the null model had the lowest AICc, the model with the with the next-lowest AICc value had plot ID as a random effect. To further examine the effect of plot ID, we conducted a two-sample t-test comparing differences in mean percent detection per plot. Mean percent detection was significantly higher in plot A (44%) than in plot B (15%) (Figure 3; t = 3.47, p = 0.003, df = 16, 95% CI = 0.11, 0.47).

The probability of detecting all plants in a single survey (equation 1) ranged from 7.59 x 10^{-4} % to 8.89% (Table 2). Achieving 95% confidence in detecting at least one plant in our survey plots (equation 2) would require a minimum of two to four surveys (Table 3).

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DISCUSSION

Because of their thorough nature, we predicted that structured surveys would detect a greater percentage of plants than unstructured surveys. However, although we found no significant difference, mean percent detection was slightly lower in structured surveys than in unstructured surveys. This was unexpected, as surveyors in structured surveys should theoretically have covered 100% of the plot area by following the transects, increasing the chances of encountering and thus detecting a plant. Although mean percent area covered was on average higher in structured surveys than in unstructured surveys, none of the surveys covered 100% of the plot area (see Table S1). We believe that the structured survey methodology, which involved following transects in Google Earth, presented several challenges potentially resulting in fewer detections than expected. First, the GPS error may have led surveyors to believe they were in one transect when they were in another. Second, since the transects were not physically marked on the ground with flags or ropes, and the plots were situated in densely regenerating forests, surveyors may have had difficulty maintaining a straight line. Third, although we chose a 5 m buffer size based on Henderson's (2009) recommendations, having a narrower buffer size could have potentially increased detectability. Fourth, by following transects on their phones, surveyors spent more time looking at the transect map on their devices. For future structured surveys in dense forests or large areas, it would be advantageous, if possible, to mark the transects with ropes or flags before conducting the surveys and/or creating narrower transects. Pre-marking the transects could be useful when the objective is to monitor critically endangered species or eradicate invasive species, as failure to detect even a few individuals could undermine a

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management effort. However, we note the additional logistical challenges in doing so in dense forests. Pre-marking the transects would significantly increase survey time, and therefore cost. Future studies could evaluate the effectiveness of pre-marking the transects on the number of detections relative to the time spent. Alternatively, if pre-marking transects is unfeasible, surveyors could use GPS devices to track their coverage. This would allow them to identify surveyed and unsurveyed areas, focus efforts on unsurveyed regions, and ensure comprehensive coverage of the entire study area.

We also had anticipated that unstructured surveys would be faster than structured surveys because they might only survey a portion of the study area and therefore detect a greater percentage of plants per time unit. In this case, we found the anticipated pattern, and mean percent detection per time unit was slightly higher in unstructured surveys (0.4% detections/minute) than in structured surveys (0.2% detections/minute), although this difference was not significant. However, we note that percent area covered per time unit was similar for both types of surveys. The mean area covered indicated that structured surveys covered slightly more area per minute (structured = 70 m2/minute, unstructured = 69 m2/minute) but the median indicated the opposite, that unstructured surveys were slightly faster (structured = 68 m2/minute, unstructured = 73 m2/minute). In general, these results suggest that there was high variation among surveyors in the area that they covered, the time they spent conducting the surveys, and the number of plants detected, which is a common observation in other detectability experiments, such as Hauser et al. (2022), Garrard et al. (2013), and Moore et al. (2011).

Although our results cannot be directly compared to those of Huebner (2007) and Perret et al. (2023) due to differences in experimental scope, some parallels exist. Huebner's

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(2007) timed-meander method, which was similar to our unstructured surveys, was the fastest among the techniques tested, requiring 30 minutes to survey 2 ha, while our unstructured surveys took 95 minutes for 1 ha. Huebner also found that although the timed-meander method detected the greatest number of invasive species, it was less effective at documenting species abundance and often missed inconspicuous species. Huebner thus concluded that while the timed-meander method was best for detecting species presence, more systematic approaches were preferable for abundance estimates, and recommended combining both methods for comprehensive monitoring. Perret et al. (2023) found that using a grid to subdivide 1×1 m quadrats increased detectability rates, likely because it ensured surveyors covered the entire area. This grid cell approach was similar to our structured surveys, where dividing plots into transects was also intended to maximize coverage and detectability. However, unlike Perret et al. (2023), we observed no significant difference in plant detection between survey types, probably because our transects were not physically marked and surveyors did not cover 100% of the area.

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The small variance explained in the detectability model containing survey type as a fixed effect and plot ID as a random effect, suggests that plot ID alone was not the only factor involved in the detectability of the Jack in the Pulpit plants. Unexpected differences in detectability between the two survey plots might have been because of subtle differences in the study area, study design (i.e., number of plants available for detection), or random chance.

Previous studies have demonstrated that subtle differences in the study area can significantly affect the detectability of target species. For example, Hauser et al. (2022)

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found that the presence of other species with similar characteristics can reduce the detectability of the target species. In our case, despite we made every effort to ensure the plots were as similar as possible to each other, it is possible that the plot with lower detections (plot B) might have had more large white trilliums, which can be confused with Jack in the Pulpit when both plants are in vegetative state. Therefore, even within a seemingly uniform habitat, minor variations within the study area could significantly impact detectability.

In terms of study design, there was a generally low number of plants available for detection, and plot B had fewer plants than plot A. We used a low number of plants because the goal of this study was to mimic a survey for detecting a species with low abundance, and we varied the number of plants in each plot to prevent bias in surveyor behavior. Differences in detectability between the two survey plots could possibly have been due to differences in the number of plants available for detection, although we expected similar detectability rates across plots because the area that the plants occupied within the plots was nearly identical (i.e., a difference of approximately 0.0008%, assuming the plants were on average 20 x 20 cm). Abundance is an important factor in species detectability, and we recommend that future studies continue to examine the impact of abundance on detectability. For example, Dennett and Nielsen (2019) found that abundance was likely the most influential factor in determining detection success in their experiment and that *Carex* sp. with < 5% cover were likely to be undetected. Similarly, Chen et al. (2013) found that detection probability for the forb *Galeopsis tetrahit* decreased above 2,300 m in elevation as the plant became less abundant. And Moore et al. (2011), found that plants occurring in clusters were easier to detect than those

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occurring as isolated individuals. Abundance can be studied in terms of number of individuals, area covered, and spatial distribution. In addition to studying abundance from these angles, understanding the relationship between abundance and detectability is crucial, since this relationship is not always linear. For example, McCarthy et al. (2013) found that because individuals within clusters are not detected independently of each other, increasing the number of individuals in clusters does not necessarily result in an increase in detectability.

Mean detection probability of the model with the lowest AICc (i.e., the null model) was 32.9% (95% CI = 22.9% - 44.6%), this resulted in a very low probability of finding all plants in a single survey (7.59 x 10^{-4} % - 8.89%). Other detectability experiments studying inconspicuous species with low abundance have shown similar or even lower detection rates. For example, Dennett et al. (2018) found that in a 2,500 m2 plot the detectability of *Symphyotrichum lanceolatum* plants was 20%, and in a smaller plot of 1,000 m2 the detectability of *Allium cernuum* was 0%. This means that for inconspicuous plants with low abundance, it might be difficult to conduct population censuses and determine if the population is stable, decreasing, or increasing, especially if detection rate changes over time or space. This could lead to a misinterpretation of the prevalence of a species and suboptimal prioritization of conservation efforts (Bennett et al., 2024). In addition, we found that we would need at least two to four surveys to ensure 95% detection of at least one Jack in the Pulpit plant in our study plots. This suggests that for presence / absence surveys, particularly for species of conservation concern with low abundances or invasive species at the early stages of invasion, results of a single survey could be highly misleading. Similarly, Garrard et al. (2015) found that adjusting survey duration was

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crucial, as standard environmental impact assessment protocols failed to detect an endangered species at half of its known sites. Garrard et al. (2015) found that they would need 2 hrs/ha and Moore et al. (2011) found they would need 8 hrs/ha, to achieve a 95% detection probability of their target species under the most favorable survey conditions. We estimate that in our best scenario (i.e., only two surveys needed), we would need approximately 3.5 hrs/ha to detect a Jack in the Pulpit plant with 95% confidence using the average duration of our surveys. Whenever feasible, it would be recommended to consider conducting multiple surveys or adjusting survey time to achieve a predetermined detection confidence. Moore et al. (2014) provide a framework for deciding how many surveys to conduct when detectability varies considering time constraints. If multiple surveys are conducted, it is crucial to document how the surveys were conducted and the locations of the individuals found (Henderson, 2009). This would allow for a better understanding of population trends as surveyors could re-visit sites and look for the same individuals found in previous surveys. Multiple surveys are also recommended for multi-species studies. For example, both the Alberta Native Plant Council and the British Columbia Ministry of Environment and Climate Change Strategy recommend conducting at least two field visits during the growing season for rare vascular plant surveys. Survey timing should be planned to coincide with periods when plants' diagnostic features are most visible, which can vary with elevation, latitude, and weather. In some cases, surveys over multiple years may be necessary, as some plants can remain dormant for years in the soil seed bank (Alberta Native Plant Council, 2012; British Columbia Ministry of Environment and Climate Change Strategy, 2018). In our study, Jack in the Pulpit plants were in a vegetative state, so their diagnostic leaves were visible throughout spring and

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summer. If the plants had been older and produced spathes or fruits, surveys would be best timed either for late spring, when the spathes are visible and large white trilliums are flowering; or late summer when Jack in the Pulpit plants produce their showy red berries.

Designing detection experiments is challenging (Hauser et al., 2012), yet these experiments offer valuable insights into the factors influencing the detectability of organisms, enabling us to use that information to improve the design of future survey protocols. Increasing the number of surveys would strengthen our experiment but would also present several challenges. In our study, surveyors tried each type of survey once. If surveyors could perform each type of survey multiple times, we could analyze the data as a paired study. However, this would require more plots, which could increase variability in detectability, as even similar plots may have subtle differences. In addition, conducting multiple surveys of each kind might lead surveyors to progressively improve at detecting the plants, as they would have more experience finding Jack in the Pulpit plants in mixed forests. Alternatively, we could add more surveyors to our study plots, but doing so could result in trampling. Adding more surveyors would also require spacing surveys over a longer period to avoid surveyor overlaps in the plots, which could result in detectability differences due to changes in phenology. While some guidelines for conducting rare species surveys are available (e.g., Henderson 2009; Alberta Native Plant Council, 2012; British Columbia Ministry of Environment and Climate Change Strategy, 2018; Ontario Ministry of the Environment, Conservation and Parks, accessed April 2025), these guidelines have rarely been tested for their efficiency. Testing the efficiency of survey protocols, in terms of detections per time unit and survey effort, allows us to develop

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protocols that optimize detectability success while accounting for time, human, and financial constraints.

CONCLUSION

In this study we tested the efficiency of two survey protocols, structured and unstructured surveys, for the detection of an inconspicuous forest understory plant with low abundance. Both protocols yielded a similar number of plant detections, with unstructured surveys detecting slightly more plants per time unit, and structured surveys covering slightly more plot area. In cases where time is a critical factor, unstructured surveys might be more efficient due to their higher plant detection rate per time unit. Conversely, when the habitat preferences of the target species are unknown, structured surveys might be better to ensure a comprehensive coverage of the study area. However, it is important to note that the differences between the two protocols tested here were not statistically significant, and there was variation among surveyors and significant variation between plots. As a result, we cannot conclude that one method was more efficient than the other.

We recommend that future studies continue to examine the impact of abundance on detectability, and evaluate the cost-effectiveness of pre-marking transects on the number of detections relative to the time spent. Additionally, we suggest calculating the minimum number of surveys needed to achieve a predetermined detection confidence to optimize detectability success while considering time and budget constraints. Testing the efficiency of survey protocols can provide valuable information to direct conservation and management efforts.

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AUTHOR STATEMENTS

Competing interests

The authors declare that there are no competing interests.

Data availability

Raw data and R code can be found in the Supplementary Material accompanying this manuscript.

REFERENCES

Alberta Native Plant Council. (2012). ANPC Guidelines for Rare Vascular Plant Surveys in Alberta -2012 Update. https://anpc.ab.ca/wp-content/uploads/2015/01/Guidelines-For-Rare-Plant-Surveys-in-AB-2012-Update.pdf

Bennett, J. R., Edwards, B. P., Bergman, J. N., Binley, A. D., Buxton, R. T., Hanna, D. E., ... & Rytwinski, T. (2024). How ignoring detection probability hurts biodiversity conservation. Frontiers in Ecology and the Environment, e2782. https://doi.org/10.1002/fee.2782

British Columbia Ministry of Environment and Climate Change Strategy. (2018). Inventory and Survey Methods for Rare Plants and Lichens. https://www2.gov.bc.ca/assets/gov/environment/natural-resource-stewardship/nr-laws-policy/risc/inventory_and_survey_methods_for_rare_plants_and_lichens.pdf

Brooks, M. E., Kristensen, K., van Benthem, K. J., Magnusson, A., Berg, C. W., Nielsen, A., Skaug, H. J., Maechler, M., & Bolker, B. M. (2017). glmmTMB balances speed and

Draft

flexibility among packages for zero-inflated generalized linear mixed modeling. The R Journal, 9(2), 378-400. https://doi.org/10.32614/RJ-2017-066

Chen, G., Kéry, M., Zhang, J., & Ma, K. (2009). Factors affecting detection probability in plant distribution studies. Journal of Ecology, 97(6), 1383–1389. https://doi.org/10.1111/j.1365-2745.2009.01560.x

Chen, G., Kéry, M., Plattner, M., Ma, K., & Gardner, B. (2013). Imperfect detection is the rule rather than the exception in plant distribution studies. Journal of Ecology, 101(1), 183-191. https://doi.org/10.1111/1365-2745.12021

Dennett, J. M., & Nielsen, S. E. (2019). Detectability of species of *Carex* varies with abundance, morphology, and site complexity. Journal of Vegetation Science, 30(2), 352–361. https://doi.org/10.1111/jvs.12713

Dennett, J. M., Gould, A. J., Macdonald, S. E., & Nielsen, S. E. (2018). Investigating detection success: lessons from trials using decoy rare plants. Plant Ecology, 219(5), 577–589. https://doi.org/10.1007/s11258-018-0819-1

Esri Inc (2016). ArcGIS Desktop 10.5. Redlands, CA. Software.

Garrard, G. E., McCarthy, M. A., Williams, N. S. G., Bekessy, S. A., Wintle, B. A., & Ramula, S. (2013). A general model of detectability using species traits. Methods in Ecology and Evolution, 4(1), 45–52. https://doi.org/10.1111/j.2041-210x.2012.00257.x

Garrard, G. E., Bekessy, S. A., McCarthy, M. A., & Wintle, B. A. (2015). Incorporating detectability of threatened species into environmental impact assessment. Conservation Biology, 29(1), 216-225 https://doi.org/10.1111/cobi.12351

Draft

© The Author(s) or their Institution(s)

Hauser, C. E., & McCarthy, M. A. (2009). Streamlining “search and destroy”: Cost-effective surveillance for invasive species management. Ecology Letters, 12(7), 683–692. https://doi.org/10.1111/j.1461-0248.2009.01323.x

Hauser, C. E., Moore, J. L., Giljohann, K. M., Garrard, G. E., & McCarthy, M. A. (2012). Designing a detection experiment tricks and trade-offs. Eighteenth Australasian Weeds Conference. https://caws.org.nz/old-site/awc/2012/awc201212671.pdf

Hauser, C. E., Giljohann, K. M., McCarthy, M. A., Garrard, G. E., Robinson, A. P., Williams, N. S. G., & Moore, J. L. (2022). A field experiment characterizing variable detection rates during plant surveys. Conservation Biology, 36(3). https://doi.org/10.1111/cobi.13888

Henderson, D. C. (2009). Occupancy Survey Guidelines for Prairie Plant Species at Risk. https://www.npss.sk.ca/docs/2_pdf/Rare_Plant_Occupancy_Survey_Guidelines.pdf

Huebner, C. D. (2007). Detection and monitoring of invasive exotic plants: a comparison of four sampling methods. Northeastern Naturalist, 14(2), 183-206. https://doi.org/10.1656/1092-6194(2007)14[183:DAMOIE]2.0.CO;2

Kéry, M., & Gregg, K. B. (2003). Effects of life-state on detectability in a demographic study of the terrestrial orchid *Cleistes bifaria*. Journal of Ecology, 91(2), 265-273. https://doi.org/10.1046/j.1365-2745.2003.00759.x

Manitoba Conservation Data Centre. (n.d.). Plant species and plant communities of conservation concern in Manitoba. Manitoba Natural Resources and Northern Development. Accessed March 2023. https://www.manitoba.ca/nrnd/fish-wildlife/cdc/pubs/plant-list-mbcdc-2021-nov.pdf

Draft

© The Author(s) or their Institution(s)

McCarthy, M. A., Moore, J. L., Morris, W. K., Parris, K. M., Garrard, G. E., Vesk, P. A., Rumpff, L., Giljohann, K. M., Camac, J. S., Bau, S. S., Friend, T., Harrison, B., & Yue, B. (2013). The influence of abundance on detectability. Oikos, 122(5), 717–726. https://doi.org/10.1111/j.1600-0706.2012.20781.x

Moore, J. L., Hauser, C. E., Bear, J. L., Williams, N. S. G., McCarthy, M. A., & Parkhurst, D. (2011). Estimating detection-–effort curves for plants using search experiments. Ecological Applications, 21(2), 601–607. https://doi.org/10.1890/10-0590.1

Moore, A. L., McCarthy, M. A., Parris, K. M., & Moore, J. L. (2014). The optimal number of surveys when detectability varies. PLoS ONE, 9(12). https://doi.org/10.1371/journal.pone.0115345

Nature Conservancy of Canada. (n.d.). Jack-in-the-pulpit. Accessed March 2023. https://www.natureconservancy.ca/en/what-we-do/resource-centre/featured-species/plants/jack-in-the-pulpit.html

NatureServe (n.d.). Jack-in-the-pulpit. Accessed April 2025. https://explorer.natureserve.org/Taxon/ELEMENT_GLOBAL.2.132762/Arisaema_triphyllum

Ontario Ministry of the Environment, Conservation and Parks. (n.d.). Species at risk surveys. Accessed April 2025. https://www.ontario.ca/page/species-risk-surveys

Perret, J., Besnard, A., Charpentier, A., & Papuga, G. (2023). Plants stand still but hide: Imperfect and heterogeneous detection is the rule when counting plants. Journal of Ecology, 111(7), 1483-1496. https://doi.org/10.1111/1365-2745.14110

Draft

© The Author(s) or their Institution(s)

R Core Team. (2023). R: A language and environment for statistical computing (Version 4.3.1). R Foundation for Statistical Computing. https://www.R-project.org/

Thompson, S.A. (2023). *Arisaema triphyllum*. In: Flora of North America North of Mexico [Online]. 25+ vols. New York and Oxford. Vol. 22. Accessed October 2024. http://floranorthamerica.org/Arisaema_triphyllum.

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TABLES

Table 1. Selected model parameters

Model: GLMM survey type (fixed effect) and plot ID (random effect)				
	Estimate	Std. error	z value	Pr(>|z|)
Intercept	-0.93157	0.59997	-1.553	0.120
Unstructured survey	0.05053	0.52940	0.095	0.924
Model: Null model (~ 1)				
	Estimate	Std. error	z value	Pr(>|z|)
Intercept	-0.7147	0.2545	-2.808	0.00498

Table 2. Percent probability of finding all plants in a single survey as per the calculations in equation 1, k = total number of plants available for detection, p = probability of detection.

	k = 5 – plot A	k = 3 – plot B	k = 8 – mean plots
p = 33% (overall detectability rate)	0.38 %	3.55 %	0.01 %
p = 22.9% (null model, detection probability estimate – lower bound)	0.06%	1.20%	7.59×10^{-4} %
p = 44.6% (null model, detection probability estimate – upper bound)	1.77 %	8.89 %	0.16 %

Table 3. Minimum number of surveys needed to detect at least one plant in our survey plots as per the calculations in equation 2, k = total number of plants available for detection, p = probability of detection.

	k = 5 – plot A	k = 3 – plot B
p = 33% (overall detectability rate)	2	3
p = 22.9% (null model, detection probability estimate – lower bound)	3	4
p = 44.6% (null model, detection probability estimate – upper bound)	2	2

FIGURES

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Figure 1. Jack in the Pulpit (*Arisaema triphyllum*) left, and large white trillium (*Trillium grandiflorum*) right, both in vegetative state.

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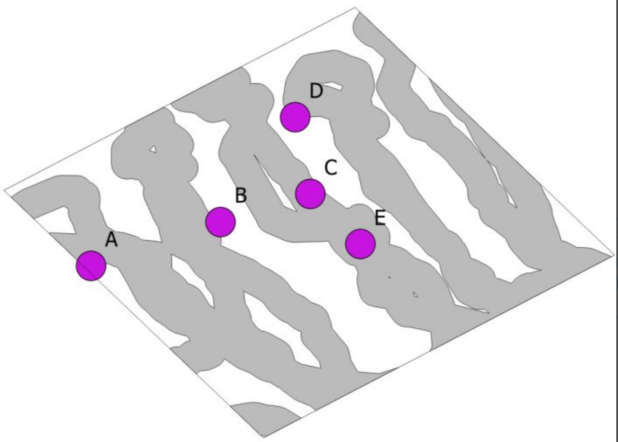
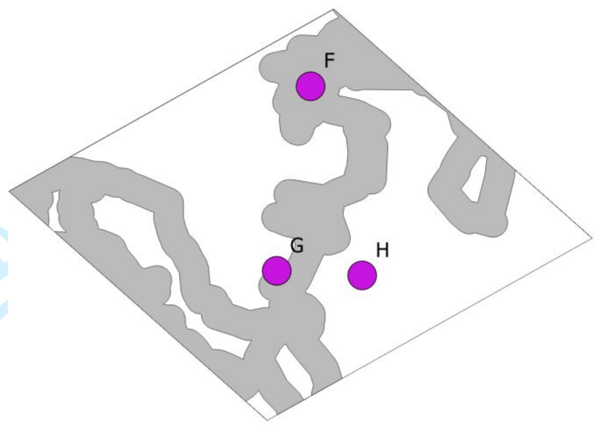
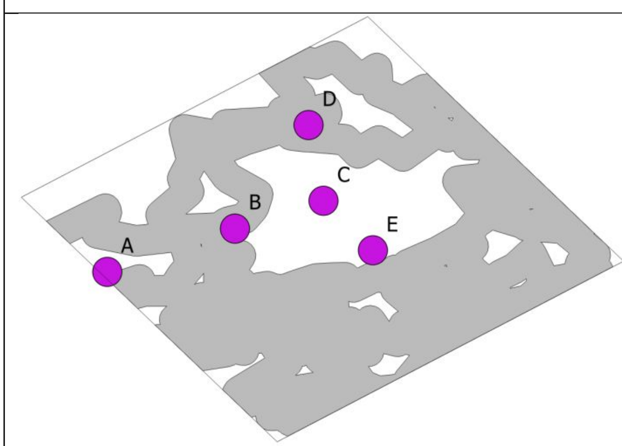
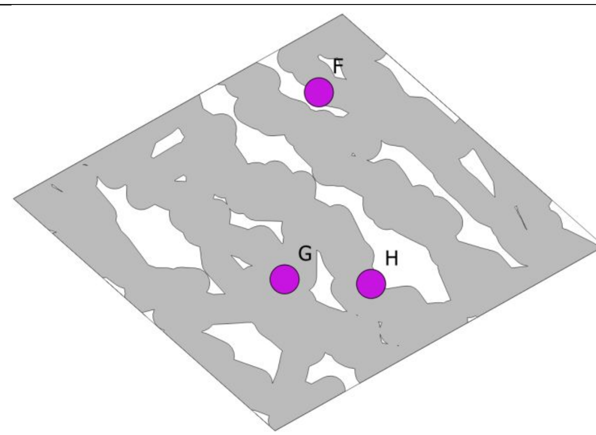
Plot A	Plot B
	
Structured Survey – Plot A	Unstructured Survey – Plot B
	
Unstructured Survey – Plot A	Structured Survey – Plot B
	

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Figure 2. Photos of study plots with examples of paths that surveyors followed when conducting structured and unstructured surveys. Letters indicate the location of plants inside the plots. See Table S1 for more information about surveyor tracks.

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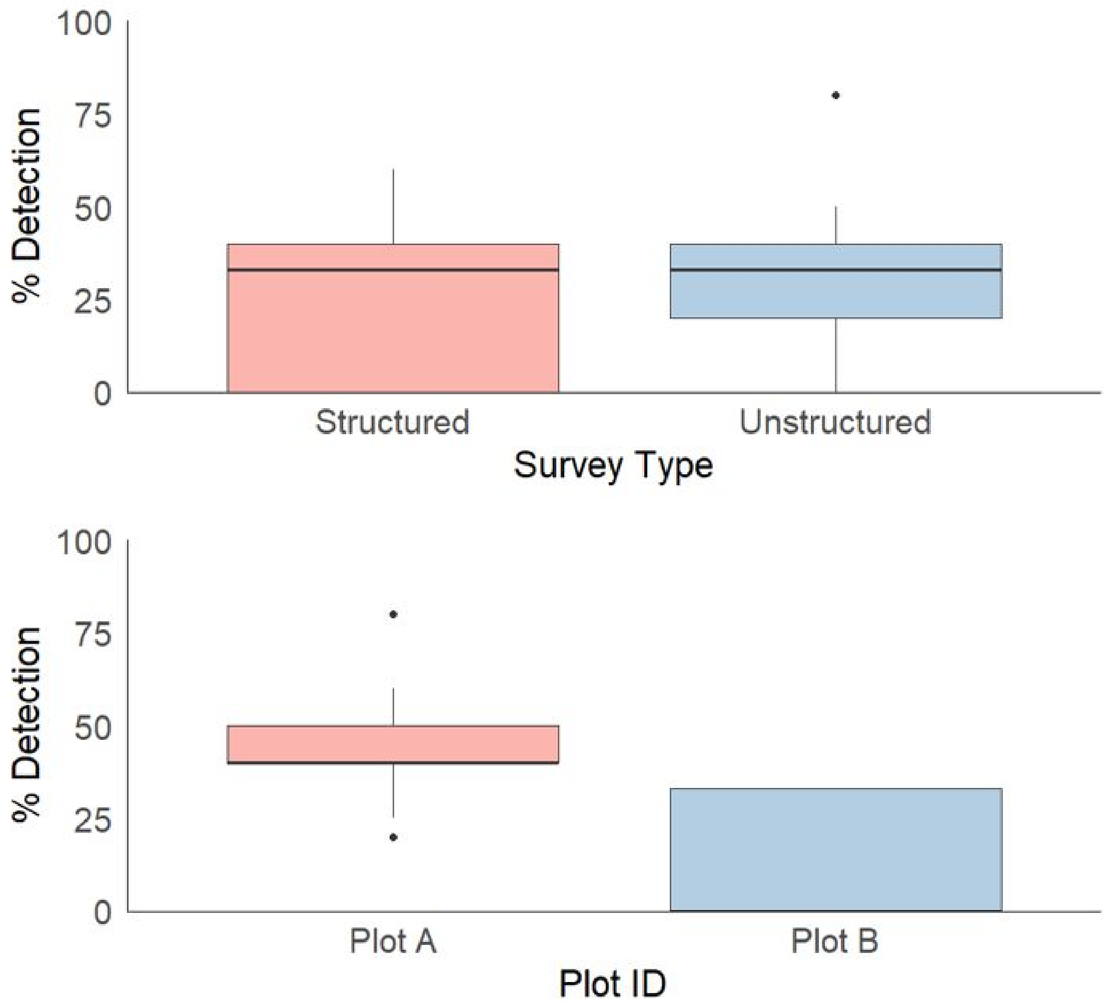

Figure 3. Percent detection success per survey type (p = 0.6) and plot (p = 0.003). Lower and upper hinges in the boxes correspond to the first and third quartiles (the 25th and 75th percentiles). Upper whiskers extend from the upper hinge to the largest data point that is no more than 1.5 the interquartile range (IQR) above the upper hinge. Lower whiskers extend from the lower hinge to the smallest data point that is at least 1.5 IQR below the lower hinge. Data points beyond the whiskers are outliers.

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