A monitoring protocol for assessing plant diversity on small private woodlots in Southern Ontario under the OWA Forestry Cooperative Pilot Project

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Executive summary

This capstone project report describes the development of an adapted protocol for assessing and monitoring plant diversity in Southern Ontario. In Southern Ontario, old unmanaged private conifer plantations are gaining attention and are beginning to be thinned to create conditions for the regeneration of native hardwood forests. The Ontario Woodlot Association, the sponsor of the Forestry Cooperative Pilot Project, wanted to explore a rapid and effective sampling method that could be used by landowners to generate monitoring feedback. The adapted method is developed based on a methodology that adapts the Vegetation Sampling Protocol for easy implementation and increased efficiency for surveyors with different backgrounds. Preliminary results show that the protocol can provide a rough estimate of biodiversity distribution patterns and trend for on-going use. The protocol will be further refined in the future through testing at additional sites.

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1. Introduction

The main ownership of forests in Southern Ontario is concentrated in the non-public sector, with a significant area of private woodlots (Government of Ontario, 2021). The average size of these woodlots is about 6 to 8 ha, which is smaller than public forests (Watkins, 2011; Kim, 2020). The origin of these private woodlots and plantations has a close relation to early European settlement and the extensive deforestation thereafter, which also changed the structure and distribution patterns of the remaining forests (Parker et al., 2008). During this period, most of forests were cut to provide timber and the cleared land was used for agricultural purposes; some small patches were retained to provide firewood and other forest products (Dansereau & deMarsh, 2003; Kim, 2020). Then, parts of agricultural lands unsuitable for growing crops were abandoned and reconverted to forest patches, and eventually resulted in a small and fragmented distribution of private woodlots (Butt, 2010; Schwan et al., 2013; Kim, 2020).

In the early 20th century, plantations were introduced to deforested land as an alternative to restore degraded landscapes and rebuild organic soils (Schwan et al., 2013; Rotherham, 2017). These plantations, which are dominated by coniferous species such as red pine, were once desirable for their ability to establish on poor soils and provide a large portion of the forest cover in Southern Ontario (Parker et al., 2008). Management of coniferous forest plantations on public lands has been relatively well established and effective over a long time of professional planning and systematic practice; however, plantations on smaller private woodlots are commonly lacking in support for regeneration and conservation activities due to the limited knowledge and resources available to landowners (Kim, 2020; Shukla, 2021). Moreover, the small size and scattered distribution create barriers to machinery accessibility and operability (Kant, 2009; Kim, 2020).

Thinning has been proven to stimulate the development of understory vegetation by opening the canopy and accelerate the transition from artificial plantations to more diverse native forest compositions; while undisturbed plantations have been found lacking the ability to provide natural regeneration and varied ecosystem services due to high stem densities, thick litter layers, and monoculture plantings (Elliot et al., 2008; Parker et al., 2008). However, since these stands still have the potential to provide ecological and social benefits, the issues of unmanaged coniferous plantations have been matters of ongoing concern over decades (Parker et al., 2001; Parker et al., 2008).

In several temperate forest regions, coniferous plantations have been managed and restored through various intervention operations. However, as forest inventory surveys are primarily conducted on publicly owned lands, there is still a lack of up-to-date information and data on the recovery status of private woodlots and their plantations in Southern Ontario (Schwan & Elliott, 2010). Furthermore, most current biodiversity monitoring approaches and diversity indices are typically used to assess and analyze changes at the landscape-scale and may fail to reflect differences in land use on properties at fine-scale level (Imran et al., 2021). Also, given that the restoration and evolution will be a long-term process, meticulous and regular inventories often require more time and expenditures that cannot be afforded by landowners. Therefore, there is a need to develop a time- and economically feasible protocol to assist landowners to conduct simple and rapid biodiversity monitoring and assessment at small scales with the expectation of obtaining patterns of thinning intervention impacts on diversity within private woodlots and plantations.

The following sections will provide background information and instructions for data collection and on-going plant diversity monitoring plan under the forest owner cooperative pilot projects launched by The Ontario Woodlot Association (OWA). Using a private woodlot in the Lake Simcoe watershed as an example, this paper will show how the minimum requirements data collected by adapted protocol can be used to determine the baseline condition of the woodlot and to develop a map to estimate plant diversity variation within the private property. Aside from that, this paper will discuss how landowners will benefit from the information provided by the inventory and on-going monitoring and expects to engage stakeholders or interested parties from different backgrounds in the project to help achieve the closely related biodiversity objectives of the cooperative forestry pilot projects.

2. Literature review

2.1 Biodiversity

Biodiversity is a shortened form of "Biological diversity". The term has become very popular since its introduction by Edward Wilson in 1989 and is used by environmental biologists, environmentalists, policy makers with many outsiders, but the meaning behind the term remains ambiguous in many cases (Wilson, 1985; Wilson & Peter, 1990; Supriatna, 2018). According to Wilson and Peter (1990), biodiversity is broadly defined as the diversity of organisms and its processes, which includes species diversity, genetic diversity and variation among communities and ecosystems. It is worth noting that this definition requires users to be aware of the different dimensions of biodiversity, considering that any biota can be characterized by its taxonomic, ecological, and genetic diversity, and that the way these characteristics change over time and space is a key feature of biodiversity (Supriatna, 2018). Therefore, the assessment of biodiversity needs to consider the variability within biota and their interactions with ecosystem functions and services.

Since precise quantification of biodiversity is difficult and complex, and given that the objective of the Forestry Cooperative Pilot Project at this stage is to find a way to detect any potential impacts of thinning in private woodlots, the type of biodiversity at this stage should first be identified and determined. From the perspective of ecology, it is often the case that researchers may focus on species diversity, since biodiversity in its simplest form is the diversity of different types of organisms present and interacting in an ecosystem (Kumar et al., 2021). Several studies have also demonstrated that community and ecosystem processes are correlated with species diversity; it is the most common representation of ecological diversity (Tilman et al., 1997; Hamilton, 2005). Therefore, using plant species diversity and its associated indices for analysis would be a relatively straightforward approach.

2.2 Plant diversity indices

The taxonomic dimension of biodiversity contains many components, each of which can be operationally defined by a number of indices. Biodiversity indices provide researchers with a specific, standardized method to discuss and compare biodiversity across regions (Purvis & Hector, 2000). The construction of a mathematical concepts of diversity index is a widely known method to measure species diversity with its two main aspects describing the community are species richness and evenness (Hamilton, 2005). These two measurements are commonly used as independent indices for biodiversity measurement.

Richness, or the number of species present in a given area, is the simplest and still the most commonly used metric for characterizing diversity (Whittaker, 1972; Magurran, 2005; Supriatna, 2018). The higher the number of species in a sample, the higher the species richness of the given sample. However, biodiversity cannot be measured simply by the number of species or the number of individuals in a population within a community (Austin, 1996; Supriatna, 2018). A common misconception is to totally substitute species diversity for biodiversity. Many species richness measures suffer from the problem that they are strongly dependent on sampling effort. Thus, comparing metrics from data collected with differing levels of sampling effort can be difficult and possibly misleading. Besides, considering species richness solely may make diversity homogenous, especially in areas where invasive species have been introduced. Although regional species richness may increase, it will ultimately result in impoverishment on a larger scale because invasive species do not contribute to native biodiversity and cause invaded areas to lose their own distinctive characters (Austin, 1996; Supriatna, 2018). The most relevant example of this to small private conifer plantations is that increased species richness on the property will be expected through forest management practices, as proper rotation cycles and thinning operations will help relocate nutrients and growing space, thus allowing recruitment of generic understory vegetation; however, some sensitive or rare species may have difficulty spreading or colonizing due to habitat changes caused by anthropogenic disturbances. In this case, despite the recruitment of some species, the disappearance of sensitive species from the landscape leads to unhelpful species richness at a larger scale (Supriatna, 2018; Haughian, 2018).

In fact, there are many other factors that influence biodiversity in each ecosystem than simply the species number. Quality, or the diversity and heterogeneity of species characteristics, will provide more information than quantity (Hill, 2005; Morris et al., 2014). Evenness, which is a measure of the relative abundance of different species that constitute the richness of an area (Supriatna, 2018). It refers to how close in numbers each species in an environment is. However, failure to detect rare and cryptic species when comparing communities with significantly different detect abilities will lead to artificially inflated estimates of evenness, as any evenness estimate for low-diversity systems will be mathematically limited, resulting in community diversity not being truly reflected (Robinson et al., 2014; Kvålseth, 2015). Specifically, evenness is limited by species richness and the number of observed individuals; it can be spuriously inflated when only a small number of species or individuals are observed (Gosselin, 2006; Jost, 2010; Robinson et al., 2014). Using this index alone as an indicator to explain ecosystem characteristics would be misleading and as such it should be treated with caution (Jost, 2010).

Generally, species diversity components also include dominance, and rarity of species (Wilsey et al., 2005). Dominance, as an index of species diversity is also sometimes independent of the concept when assessed and analyzed. This hypothesis is based on the assumption that pioneer communities developing after disturbance are dominated by only a few species (Frontier

1985; Nummelin & Kaitala, 2004). Dominance index detects dominance patterns by calculating the proportional abundance of the most abundant species and is used to characterize the distribution (Berger & Parker, 1970). While it is also a way to consider the combined dominance of the top two to three most abundant species by considering when there is no single species showing dominance (Lambshead et al., 1983). Rarity is often defined differently by context, nature, quality and quantity of data from different studies (Magurran, 2005; Kondratyeva et al., 2019). In general, the typology of rare plant species is defined by local population size, geographic range, and habitat specificity; when all three types are scarce, the species will be more vulnerable to extinction (Rabinowitz, 1981; Kondratyeva et al., 2019).

Interpreting any of simple indices solely will lose information. At the middle to end of the last century, diversity was usually estimated by using compound indices of richness and evenness (Wilsey et al., 2005). However, it is often criticized due to the uncertainty of the definitions and indices (Alatalo, 1981). Different compound diversity indices combine richness and evenness with different weights assigned to these attributes, however, as they are highly subjective, which in turn leads to unclear ecological meaning and mathematical limitations (Nummelin & Kaitala, 2004). Nevertheless, even if biodiversity and its indices under any concept have theoretical limitations, it may still be a useful tool from a social and political perspective, depending on its application scope and ultimate objectives (Nummelin & Kaitala, 2004). Several studies and empirical evidence suggested that the validity of compound and simple indices differs in diverse cases (Morris et al., 2014). Therefore, it is necessary to evaluate different biodiversity indices according to specific study areas and objectives to obtain relatively comprehensive information.

2.3 The need for plant diversity monitoring on small private woodlots

The ecosystems of woodlots could be habitat for numerous species. Biodiversity within private lands contributes to and influences all key ecological functions and ecosystem services that underlie agroforestry production, which include, but are not limited to, nutrient cycling, decomposition, soil formation, primary production, and gene flow (Barrios, 2007; Moonen & Bàrberi, 2008). Woodlot biodiversity also supports higher levels of ecosystem services and multifunctionality, which means that multiple ecosystem services are provided at the same time and directly affect human benefits (Allan et al., 2015). It is worth noting that these ecosystem, social and economic benefits can only be experienced if these woodlots are kept in a healthy state. Therefore, it is critical to assess key biodiversity indicators and understand how they contribute to the provision of ecosystem services in the context of long-term socio-ecological monitoring.

Southern Ontario has a landscape typical of many in eastern North America where agriculture and urban land uses dominate. The average size of small private woodlots in Southern Ontario is about 6 to 8 ha, where the plantations are predominantly monoculture and are expected to yield a steady stream of commercial timber and other forest products (Schwan & Elliott, 2010; Watkins, 2011). As a result of intensive land use management during the settlement period, the landscape today is a mixture of agricultural land with scattered and small patches of remnant woodlots and urban areas (Dansereau & deMarsh, 2003; Butt, 2010; Schwan et al., 2013). Not only has forest cover been lost but the structure and species composition of the remaining forests has been dramatically altered (Parker et al., 2008). Fragmented plantations make access and operations difficult for timber harvesting and transporting, resulting in high operations costs. For many years, it has been a big challenge for landowners to access and utilize the resources and funding to properly and timely take care of their woodlands. These barriers prevent private woodlots on this land from being as ecologically and economically productive as they could be. Unmanaged plantations are disappearing or collapsing as they fail to support natural regeneration; individual trees in plantations become slow growing and more vulnerable to natural disturbances (Ontario. Ministry of Natural Resources., 1986).

The Community Forestry Co-operative pilots launched by The OWA are designed to provide landowners with an affordable way to manage their forests. By practicing best forest management to enable their plantations to develop more biodiverse systems that are available to everyone. Therefore, there is a need to assess and monitor the trends in biodiversity within the private properties participating in the pilot projects following management operations interventions. In the areas where the two pilot projects were conducted, the first thinning has been completed on some properties and is scheduled to take place on other participating ones. After the first critical thinning, subsequent operation will occur every 10 to 15 years until the remaining trees reach 80 to 100 years of age (LandOwner Resource Centre et al., 2011; Shukla, 2021). The thinning mimics natural disturbance. The canopy gap created by the first thinning provides space and resources for pioneer species to re-recruit, creating a suitable mixed-species forest habitat and encouraging succession to continue over time (LandOwner Resource Centre et al., 2011; Shukla, 2021). However, as land size and utilization are allocated in different ratios across private properties, the composition of plant communities is likely to vary in response to landowner interests, and the effects of thinning interventions on species diversity recovery within small private woodlots may be different (Schafer & Just, 2014). Therefore, there is a need to assess and monitor the trends in biodiversity within the private properties participating in the pilot projects following management operations interventions. The current lack of a planned and long-term monitoring program at fine scales makes it difficult to determine how biodiversity changes within different property scenarios and over time, how best forest management practices affect biodiversity, or what ecosystem service impacts this is. There is an urgent need for a biodiversity monitoring program that systematically quantifies biodiversity indicators associated with key ecosystem services and socio-ecological outcomes on plantations.

2.4 Challenges of assessing plant diversity on small private woodlots

Designing and conducting plant diversity studies and monitoring is inherently difficult, including taxonomic aspect, phenology aspect as well as rare species issues (Lambshead et al., 1983). Plant identification in the field is challenging for landowners. Identifying and measuring all species and biodiversity within a single property is time-consuming and almost impossible. Generally, attractive, charismatic plant species will be more favored to landowners and the public who are more willing to sample familiar species; the morphological and size variability of the different growth stages, as well as the presence of subspecies and variants, also create obstacles to field identification by non-specialists (Duelli, 1997; Stohlgren, 2007).

Another difficulty is uneven distribution of individual number in each species within each property; the majority of species only have few individuals in its population (Stohlgren, 2007). According to the previous field survey data, it might be possible that more than 50% of species recorded less than 1% coverage (Stohlgren, 2007). Besides, most recent studies on plant diversity have tended to focus on the mean levels of biodiversity for large area at landscape-scale, while neglecting the differences and complexity among diverse small forest patches. Previous studies have proven that at the fine scale, especially on private properties like farmland, biodiversity levels may vary greatly among patches due to different soil fertility and uneven species distribution (Berg, 2012; McClellan et al., 2018). Thus, although there may be an improving trend in biodiversity at the landscape scale, biodiversity within some properties may be significantly below the average.

Surveys and monitoring are expensive, especially when these activities are conducted by landowner themselves (Stohlgren, 2007). In addition, for some landowners, profits from woodlot are not the majority income; some of the properties may be even used only as vacation sites or to provide ecological services, which means that the total time spent on the survey and the transportation will also be a challenge (Dansereau & deMarsh, 2003; Kim, 2020). Therefore, it is necessary to select sampling methods based on simple and rapid criteria and easily interpretable biodiversity indices that are optimal in terms of time and cost, while providing the most valuable information to support ongoing monitoring and assessment of properties by landowners and professional foresters.

3. Objectives

The first objective of this project is to evaluate and select appropriate plant diversity indices based on easy and cost-effective demand of landowners.

The second objective is to develop a protocol to monitor plant diversity and describe the results from the preliminary test. How this data can be used to estimate the general biodiversity trend and distribution pattern are demonstrated as well.

This project will also discuss how the results of the preliminary test will inform the on-going monitoring program, as well as the applicability of the biodiversity indices and survey methods. The limitations of this adapted protocol will also be discussed by comparing to existing vegetation sampling protocol VSP.

4. Methods

4.1 Evaluation and selection of plant diversity indices

Biodiversity indices are measurements that reflect the status of a system (Alexandra, 1996). Multiple indices are necessary to fully assess biodiversity due to its multidimensional character to achieve specific objectives. Thus, an evaluation matrix was created to rate the applicability and appropriateness of various biodiversity indices based on the general bases identified by James A. Danoff-Burg (2003) and Buckland et al. (2005) with the combination of needs for a rapid inventory and simple calculations criteria by landowners. The full matrix can be found in Table 1b in the Appendix. The rating scale is from 1 to 3, where 1 means not applicable and 3 means applicable. The criteria are described as follow:

- Easy to quantify and calculate in terms of mathematical concepts

- Easy to interpret index values
- Sensitive enough to reflect impacts from forest management practices and land use changes
- Less affected by sampling effort and sample size
- Widely used in previous studies

Based on the evaluation, the selected biodiversity indices and their scores are shown in Table 1a.

Criteria	Evaluation	
	Species Richness	Exponential Shannon
Easy quantification	3	2
Easy intrepretation	3	3
Sensitivity	2	3
Small sample size	1	2
Widespread utility	3	2
Total	12	12

Table 1a. *Evaluation of selected biodiversity indices based on specific criteria.*
1 = not applicable, 3 = applicable

Species richness (SR) was used to track the total number of plant species observed in each survey per plot. Although this index allows comparisons between sites and time intervals, it is not possible to define whether changes in its index numbers imply an improvement in plant diversity on the property or an illusion due to the spread of invasive species as it treats all species equally, thus other indices need to be applied to assist (Taft et al., 2006).

Although the number of individuals is the common factor included in the biodiversity calculations, diversity indices can also be estimated from vegetation coverage data. According to Wiegleb (2016), there is no difference between the proportion of the total area covered by a species and the proportion of the total abundance of individuals of a species; however, coverage must be estimated on a basic scale, usually as a percentage (%). In this paper, the Exponential Shannon diversity index (D) will be used for calculation:

$$D = \exp\left(-\sum_{i=1}^{S} p_i \ln p_i\right)$$

$$p_i = \frac{n_i}{N}$$

where n_i represents the coverage of species I, and N represents the total abundance within the plot. Since it is the real cover that allow overlapping, the value of N will more than 100%.

This formula is thought to complement the reduced discriminatory power of the traditional Shannon-Wiener index due to the "compressed" data resulting from the logarithmic transformation by using species proportions (Jost, 2006; Shimadzu et al., 2013). MacDonald et al. (2016) also demonstrated that exponentiation is effective in improving discrimination and enabling valid measurement of the unique properties of species composition data. Moreover, it takes into account both species richness and evenness or equality.

4.2 The adapted survey method

Firstly, existing plant diversity monitoring protocols were searched for application scales and landscape types to find sampling protocols applicable to fine-scale private woodlots. Based on the search results and field training experience, the Vegetation Sampling Protocol (VSP) was considered as the basic guideline. This protocol enables a range of scales from landscape-scale to site-scale, which is also applicable to different time scales and adapted to different application scenarios according to various modules (N. Day & Puric-Mladenovic, 2012). Site data are quantitative, standardized and scientifically rigorous to support adaptive management and planning (N. Day & Puric-Mladenovic, 2012). Compared to traditional Ecological landscape classification (ELC), VSP provides and applies a more accurate classification of vegetation types and can identify the origin of communities as natural or artificial, and at which stage of succession; These application scenarios are compatible with the characteristics and evolution trends of private plantations (N. Day & Puric-Mladenovic, 2012).

Typically, high quality and detailed data collection will result in more accurate and reliable data output. However, time, expenditure and the background of landowners will limit the complexity of survey methods. However, based on experience in field courses, sampling for plant species and cover percentages solely would be time-consuming for surveyors without long-term training in plant identification and plot setting; landowners with different backgrounds and abilities will have difficulties in sampling without support from professionals.

Therefore, an adapted survey methodology was developed based on VSP and combining time and cost-effectiveness considerations for modification. The new adapted protocol will still use the basic VSP plot design with prior random plot selection and field positioning with GPS through the VSP grid. This grid was developed by Puric-Mladenovic (2015). A grid with 100m distance between each point is used in this sampling. According to VSP, this way of creating plots will reduce bias (Poulat, 2014; Lewis, 2020). Each plot has precise coordinates positioned to its center point. Sampling will use geo-referenced fixed area 400m² circular plots with a radius of 11.28m. Every plot was subdivided into four equal sections with four $1m^2$ sub-plots established along the four-cardinal direction with their central points located halfway between the plot center and its perimeter (Poulat, 2014; Lewis, 2020).

The VSP layers classification based on individual height were still used in the new adapted protocol: ground vegetation (<0.5m), shrubs (0.5-2m), sub-canopy (2-10m), and canopy (>10m). No additional consideration was given to seedling of shrubs and trees, for example, recently sprouted seedlings less than 0.5m are included in the ground vegetation layer no matter how tall it will be when mature. Some individuals of herbaceous or fern species may grow into the shrub layer, also no additional notation is needed, it is sufficient to rely on the layer classification for recording.

Collecting and identifying all plant species in the area and counting all individuals is time consuming and almost impossible. Therefore, in the adapted protocol, species identification and measurement of cover percentages for ground vegetation and shrubs layer are done only in four sub-plots, which is expected to save time. For mosses and lichens, it was unnecessary to record by species, but simply their total cover in the whole plot. For unidentified species, record them as unknown; if several unidentifiable species are present, label them by serial number.

Considering that in private woodlots and unmanaged plantation, sub-canopy and canopy species usually occupy the largest cover percentages, sampling for plants under these two layers will still cover the four sections of the complete plot, thus might reduce the error in cover percentage and total species abundance due to the reduction of the surveyed area. Sub-canopy and canopy plants are included in the sample if the midpoint of the base of the trunk is equal or less than the horizontal radial distance from the center of the plot.

The average of the cover percentages of the four sub-plots for species less than 2m in height will be used as an estimate of the species abundance in the entire plot; Similarly, for species with heights above 2m sampled in the whole plot, the average value for the four sections will be used.

To test the validity of the adapted method, this project will also use the data generated from the original VSP for the calculation of the species diversity indices. The differences between the two protocols in terms of sampling methods are listed and described in Table 2 and Figure 1 below. Results will be compared to provide more detailed information.

Fixed area plot with 11.28m radius		**Ground vegetation (<0.5m)**	**Shrubs (0.5-2m)**	**Sub-canopy (2-10m)**	**Canopy (>10m)**
	Adapted method	sub-plot	sub-plot	section	section
	VSP method	both	both	both	both

Table 2. *Comparison of the Adapted method and the VSP method in vegetation sampling design*

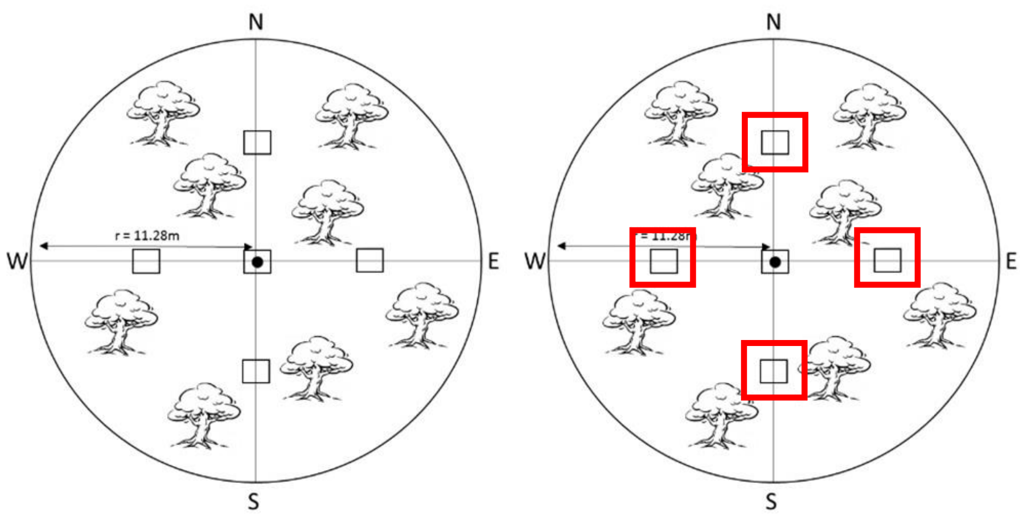


Figure 1. *Comparison of the Adapted method (right) and the VSP method (left) in sampling plot diagram.*

4.3 Data analysis process and interpolation method

The raw plot data from the survey are entered into Microsoft Access and export to Excel spreadsheet. The average cover percentage for each species within different layers in every plot has been calculated automatically by Microsoft Access.

Plant diversity within each sampling site was calculated through indices described in the previous section. To facilitate counting the species numbers, the cover percentages of seedlings for some species were combined and summed with the cover percentages of mature individuals. This part of the calculation and graphing are done using Microsoft Excel (version 16.66.1).

Once having the plant diversity per plot, the geographical information system (GIS) and Kriging geostatistical interpolation method might be used to map the distribution of biodiversity within the property per plot or by zone. Most properties in nature are continuous, however, the observation and interpretation based on GIS system are often fragmented (OLIVER & WEBSTER, 1990). The natural properties vary continuously in space with instability, so that values from geographically closer locations may also be more similar, which is the evidence for statistical interdependence (OLIVER & WEBSTER, 1990). Previous studies have demonstrated that Kriging is an effective spatial interpolation method to estimate biomass and carbon; while Oliveira et al. have shown that the method is applicable as well to mapping spatial biodiversity patterns for on-going monitoring (Sales, 2007; Meng et al., 2013; Oliveira et al., 2019). By using the Kriging tool in ArcGIS 10.8.2, it was possible to interpolate sampled plots to obtain biodiversity values of 20m x 20m pixel each, which represent 400 m^2 total sampling area per plot. This interpolation method will enable generating a biodiversity distribution map if normal distribution requirements for dataset are met.

Furthermore, an additional t-test was performed on the data obtained through each of the two protocols to determine if there was a significant difference in the mean value between them on the Shannon diversity index. This statistical analysis was performed through R Studio (version 1.4.1717).

4.4 Sampled property

In the absence of real field survey efforts, this new adapted monitoring protocol was assumed for testing at the Town of East Gwillimbury, using old data sampled by two teams of two surveyors each in August 2014 by using standard VSP. 12 plots were randomly selected for plant inventory in this study (Figure 3.). The new protocol sampled data was simulated by manually removing undesired data.

The Town of East Gwillimbury consists of 70% green space in the form of farms, forests and recreational sites (The Town of East Gwillimbury, 2022). This area is located on the southern part of Lake Simcoe Region and is part of the East Holland River sub-watershed, which is under the conservation authority of Lake Simcoe. The dominant forest types in the area are deciduous and mixed forests covering over 50% of the area, cultural plantations, and woodlands at 13%, and coniferous forests at 6.5% (Lake Simcoe Region Conservation Authority, 2022). The area has experienced intensive development and land use transformation since the late 18th century. The original native forests were largely cleared and converted to agricultural land. Later on, due to increasing environmental problems such as forest degradation and soil erosion, nurseries and conifer plantations were introduced to the area in the 1920s to help restore the deforested landscape to damaged soils (Lake Simcoe Region Conservation Authority, 2010; Lake Simcoe Region Conservation Authority, 2022). Today, forest managers are committed to turning artificial conifer plantations back into native deciduous forests through appropriate harvesting operations (Lake Simcoe Region Conservation Authority, 2022).

The sample property is located approximately 1 km east of the Holland River East Branch (Figure. 2.). The lowland landscape property is dominated by mixed forest of similar species composition; a conifer-dominated forest of approximately 30 ha is located to the south; houses and accessible trails are located on the western portion of the property; and the outer eastern side of the property is used for agricultural purposes without canopy cover (Poulat, 2014). The dataset is lacking clear documentation of thinning and other forestry management practices, but according to the Cite 4 study, approximately 70% of the species on this property are Fraxinus spp. and are likely to be entirely killed within the next 5 years by Emerald Ash Borer; furthermore, there is a significant amount of common buckthorn (*Rhamnus cathartica*) on the property that will possibly have an impact on the regeneration and diversity of native species (McCay et al. 2009; Zhang, 2014; Poulat, 2014).

Figure 2. *Property location within the East Holland River Sub-watershed in East Gwillimbury, Ontario. The yellow bounded area is the sampled property used in this project.*

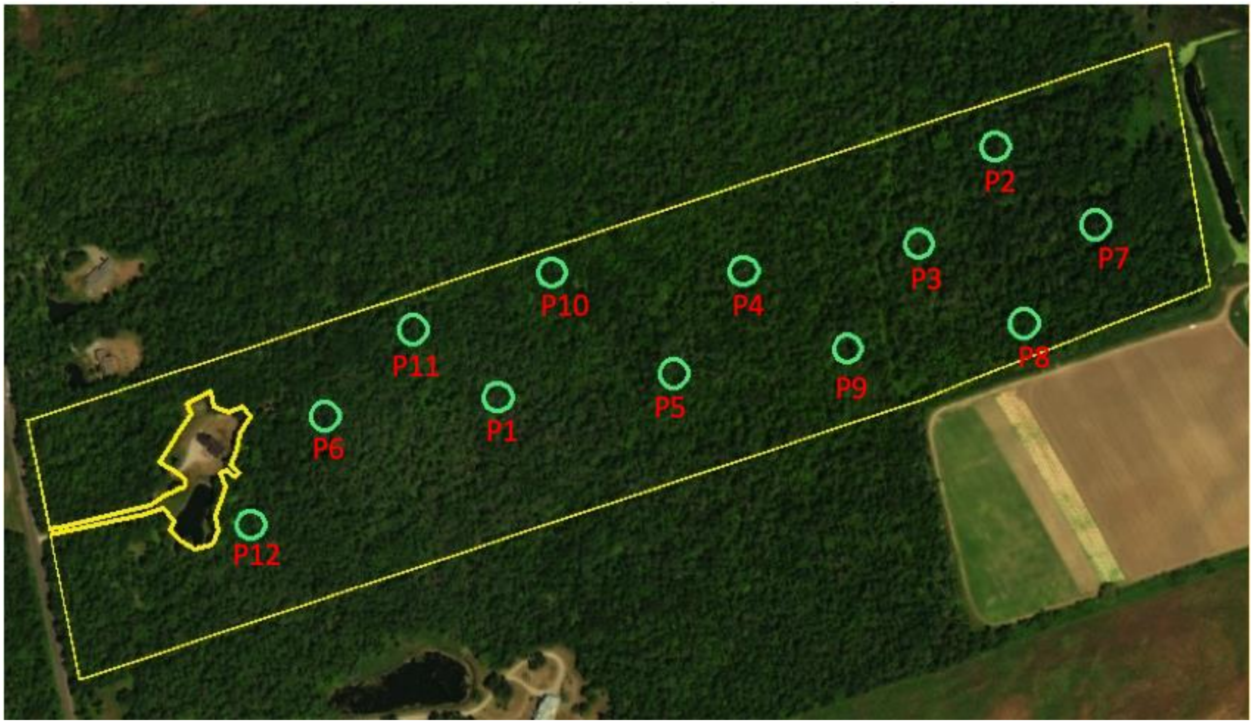


Figure 3. *12 sampling plots within the sampled property. The numbering of each plot is associated with its geographical coordinates (refer to* ***Table 3*** *in Appendix).*

5. Results

5.1 Plant diversity indices

The detailed results of species richness value, Exponential Shannon index value for each plot, and estimated in-property biodiversity indices generated by using the adapted protocol method can be found in Table 4.

The same species in different layers were counted in a single group (i.e., sugar maple appeared in gourd vegetation, sub-canopy and canopy layer but only increased the number of species by 1). It can be seen from the table that the number of species in the 12 sampled plots ranged from 8 to 26. Given that the same species would appear in different plots several times, the overall level of richness could not be obtained by simple summation; by collating and removing the redundant identical species, 71 different species were finally observed by the adapted method.

In order to calculate the Shannon index, cover percentage was transferred into species abundance data. The cover data for each species were calculated using its average and summed for each plot; abundance data for a single plot may exceed 100 since plants in different layers may overlap with each other. The coverage of each plant species in the 12 sampling plots was averaged and the total abundance sum of 71 species in total was obtained, which is around 85%. The variation of cover percentage or species abundance is from 49% to 137%. The low cover may imply an open canopy and thin cover of the ground.

The traditional Shannon-Weaver diversity index usually has a value between 1.5 and 3.5 (Ortiz-Burgos, 2015). Based on a simple mathematical conversion, the range of the Exponential Shannon diverse index can be derived to be between approximately 4.48 and 33.11. In general, the adapted method provides results that are relatively compatible with ecological logic in terms of describing biodiversity only through numerical values; the data are basically within the normal range, with only three plots showing values below the expected level.

Plot #	Species Richness	Total Abundance	Shannon Exp Index
1	18	137	3.21
2	18	101	6.83
3	26	98	5.72
4	19	49	6.32
5	8	83	2.65
6	12	133	5.05
7	13	73	5.85
8	15	77	4.63
9	21	60	4.65
10	18	79	4.18
11	19	51	5.53
12	13	87	6.39
The whole property	71	85	14.99

Table 4. *Plant diversity indices within each plot and the whole property, generated by the Adapted method.*

5.2 Plant diversity distribution

By analysing the geographical trend of the data beforehand, the ordinary kriging method was considered to map the differences since the data distribution has an ordinate pattern. The kriging interpolation maps indicate the distribution of species richness and Exponential Shannon index within the property.

According to Figure 4., the lowest values of species richness within the property occur to the west and south side, while the highest values occur to the northeast. Distribution patterns of Species richness may be influenced by different forest types, land use options, or natural disturbances (Poulat, 2014). Based on the results of the study by Poulat (2014) it appears that the area around the house (western part of the property) may have experienced more intensive management to maintain accessibility. In contrast, only eight species were recorded in the southernmost plot located in the central zone, and the vegetation cover was approximately 83%. The highest values of species richness were found in the sampling plots with the most cover provided by mosses species. Bryophytes usually live in moist coniferous or mixed forests, where relatively wet and shaded conditions facilitate the recruitment of shade-tolerant species; the second highest cover in the area is white ash (*Fraxinus americana*), which usually establishes rapidly in areas subjected to moisture in association with potential previous management activities and successional stages (Poulat, 2014; Bartels et al., 2017; Robertson et al., 2018).

Figure 5. shows the distribution pattern of the Exponential Shannon index within the property. The lowest point of its value coincides with the lowest point of species richness; the highest points occur in the northeastern and western regions.

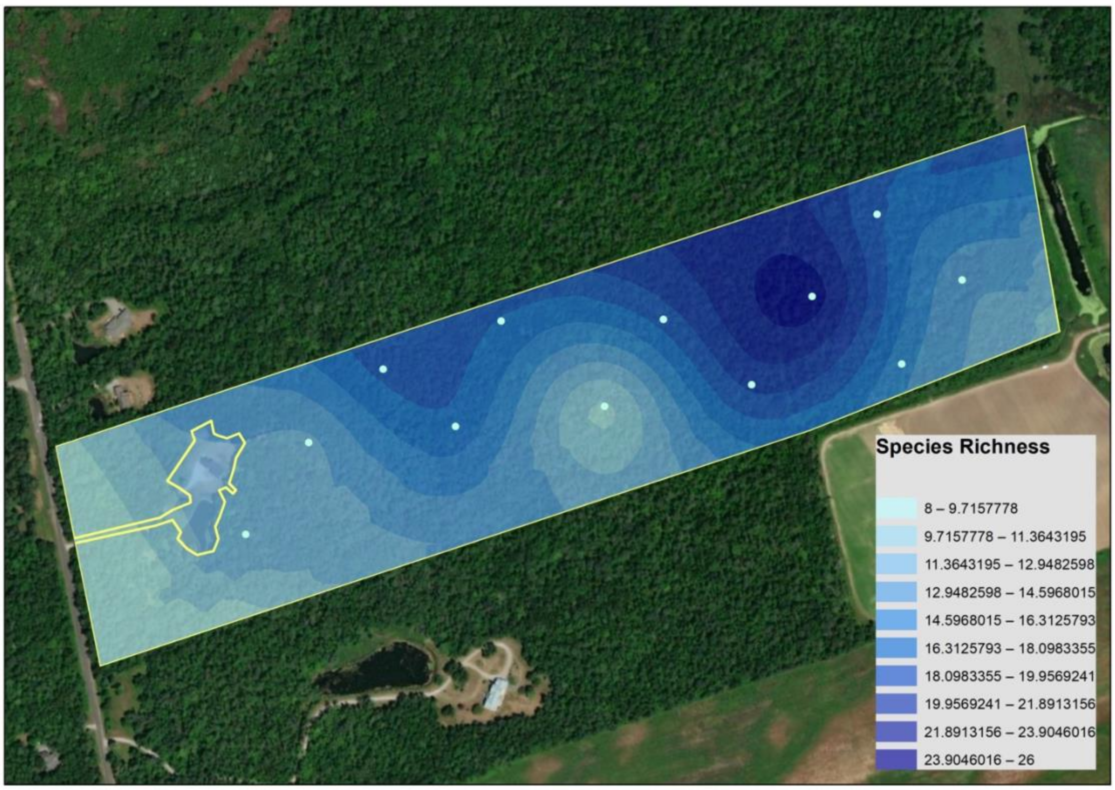


Figure 4. *Interpolation map showing the distribution of species richness in the property*

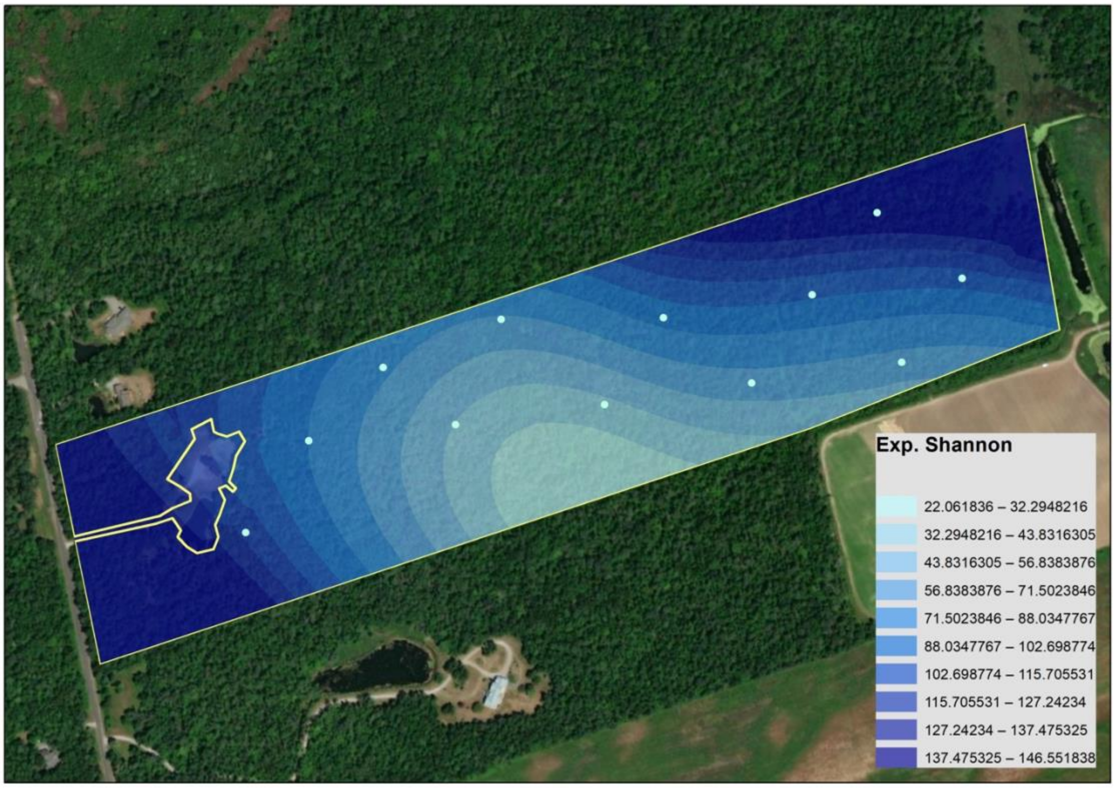


Figure 5. *Interpolation map showing the distribution of Shannon Exp index in the property*

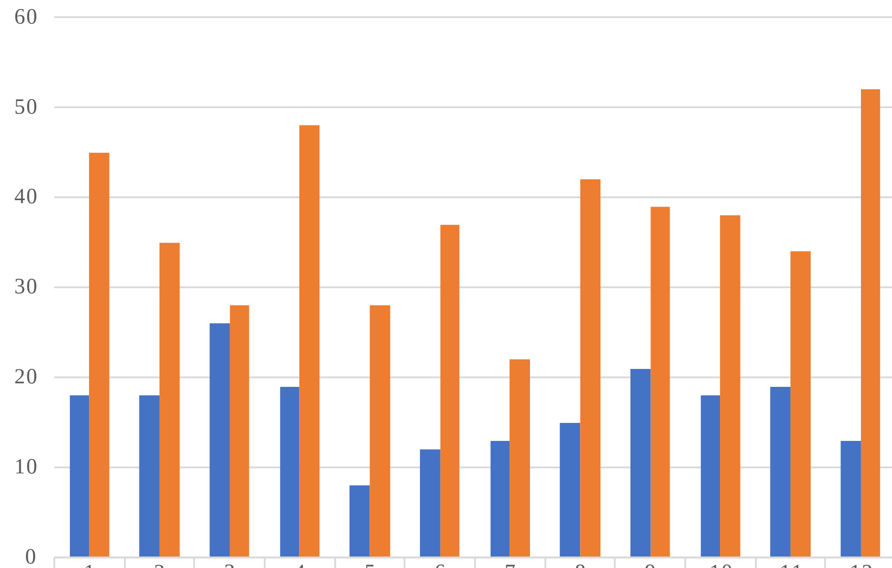
5.3 Adapted protocol vs. Vegetation Sampling protocol

To test the validity of the adapted protocol methodology, this project also uses the species coverage data from the original VSP for additional calculations and comparison to provide more detailed information.

(a) Diversity indices

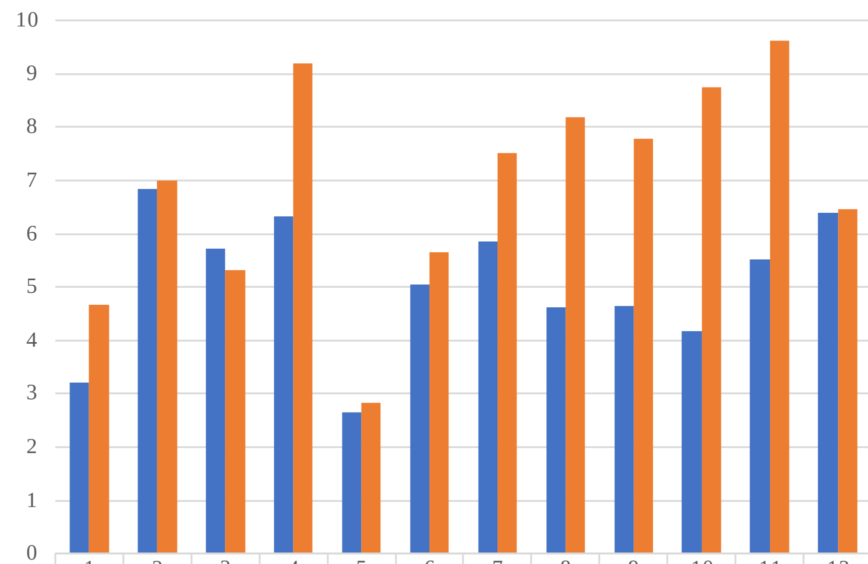
Figure 6 shows the different values of species richness obtained by the two protocols. It is clear that the adapted method ignores more than 50% of the species with low abundance (or cover %) compared to the VSP method, which is compatible with the results of Stohlgren et al. and implies that the protocol would be difficult to monitor the population changes of rare species.

Figure 7 shows the values of the Exponential Shannon index obtained for the two protocols. Again, the values from the adapted method are roughly lower than those from the VSP method; only one plot shows the opposite pattern. Considering that the Exponential Shannon index is more sensitive to changes, the traditional Shannon index is used for further comparison (Figure. 8.). It can be found that the difference in values between the two reduced a little and showed a similar distribution pattern. To further test the difference between the two overall means, a t-test test was conducted, and the results were significant (t = 2.2515, df = 22, p-value = 0.03467).



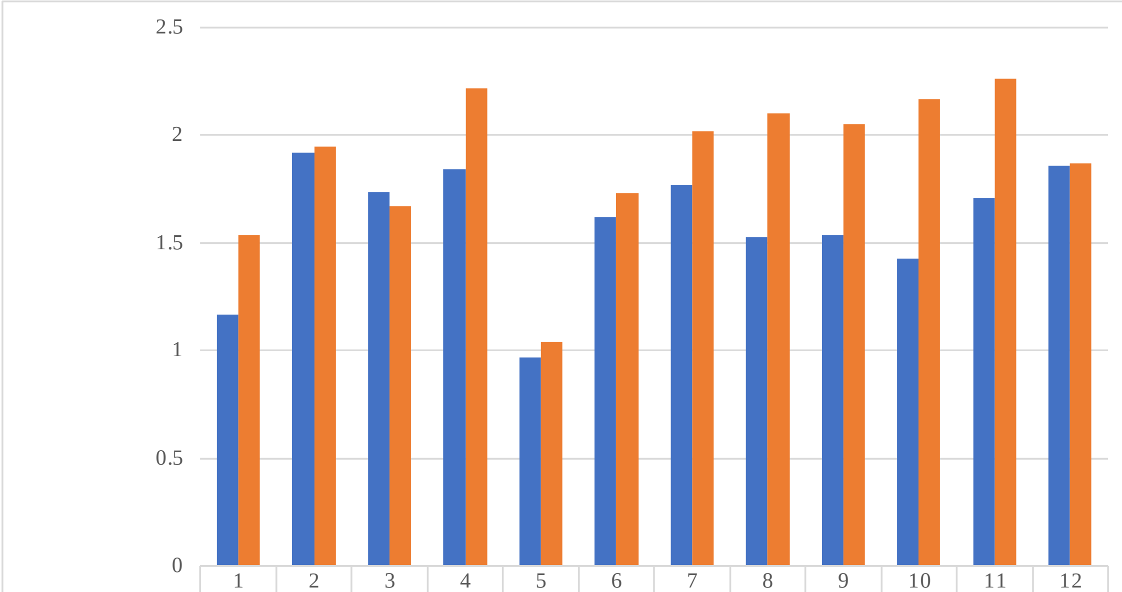
	1	2	3	4	5	6	7	8	9	10	11	12
Species Richness	18	18	26	19	8	12	13	15	21	18	19	13
Species Richness VSP	45	35	28	48	28	37	22	42	39	38	34	52

Figure 6. *Species Richness generated from Adapted method vs. VSP method*



	1	2	3	4	5	6	7	8	9	10	11	12
Shannon_Exp Index	3.21	6.83	5.72	6.32	2.65	5.05	5.85	4.63	4.65	4.18	5.53	6.39
Shannon_Exp Index VSP	4.66	7	5.31	9.2	2.83	5.66	7.52	8.19	7.79	8.74	9.62	6.47

Figure 7. *Shannon Exp Index generated from Adapted method vs. VSP method*



	1	2	3	4	5	6	7	8	9	10	11	12
Shannon Mean	1.17	1.92	1.74	1.84	0.97	1.62	1.77	1.53	1.54	1.43	1.71	1.86
Shannon Mean	1.54	1.95	1.67	2.22	1.04	1.73	2.02	2.1	2.05	2.17	2.26	1.87

Figure 8. *Shannon Index generated from Adapted method vs. VSP method*

(b) Species composition

Species abundance data for each species was used for making species composition graphs. According to Figure 9, the top three plants in terms of abundance for the adapted method, or plant cover percentage, were American elm (*Ulmus americana*) 14%; silver maple (*Acer saccharinum*) 13%; black ash (*Fraxinus nigra*) and red ash (*Fraxinus pennsylvanica*) 12%. The data obtained by the VSP method showed that the top three plants were common buckthorn (*Rhamnus cathartica*) 13%; American elm 11%; and red ash 10%. The results indicated that the adapted method provided a good representation of the dominant species composition in the property.

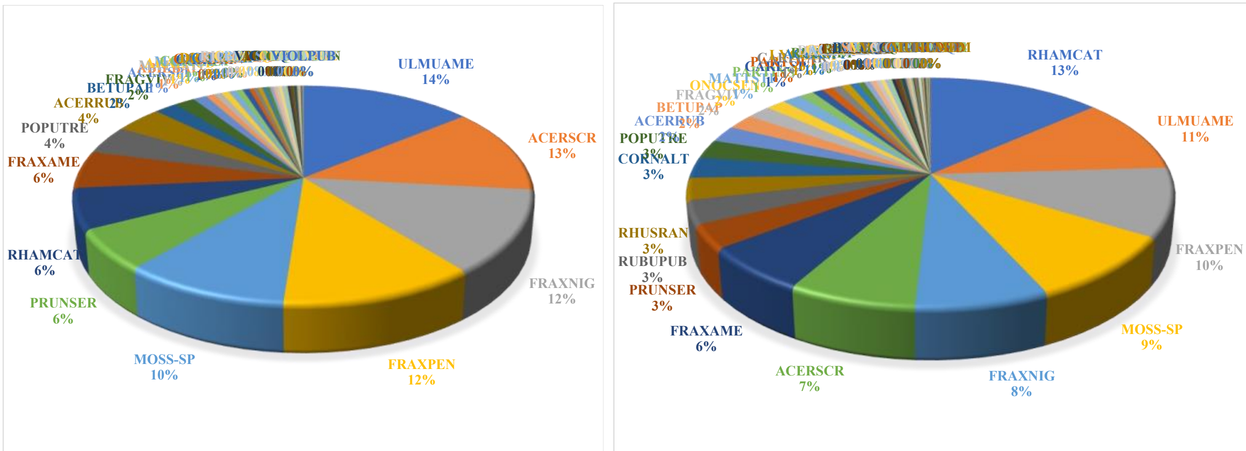


Figure 9. *Species composition generated from Adapted method (left) vs. VSP method (right)*

Species codes: ULMUAME = American Elm; ACERSCR = Silver Maple; FRAXNIG = Black Ash; FRAXPEN = Red Ash; RHAMCAT = Common Buckthorn

(c) Indicator species map

One benefit of using the VSP protocol is that it is possible to identify and map invasive and non-native species, making use of their distribution and abundance to understand their dispersal paths and possible reasons (Poulat, 2014). Considering that common buckthorn (*Rhamnus cathartica*) can grow to the sub-canopy layer and has more canopy cover, this invasive plant was used here for mapping indicator species map and comparing the ability of the two protocol methods.

The image results (Figure 10.) show that although the adapted method shows the similar ability in mapping indicator species, it misses species that are numerous but cover a small percentage, especially when these individuals are sporadically distributed within the landscape, which makes the protocol method only detect species reaching a certain abundance level. The data results (Figure 11.) show the differences generated by the two protocol methods in a more visual way. It is evident that in Plot 11, the adapted method showed no presence of common buckthorn in the area, even though the VSP method had sampled up to 24% of the species occupancy.

Figure 10. *Indicator species (Common Buckthorn) distribution map generated from Adapted method (above) vs. VSP method (below)*

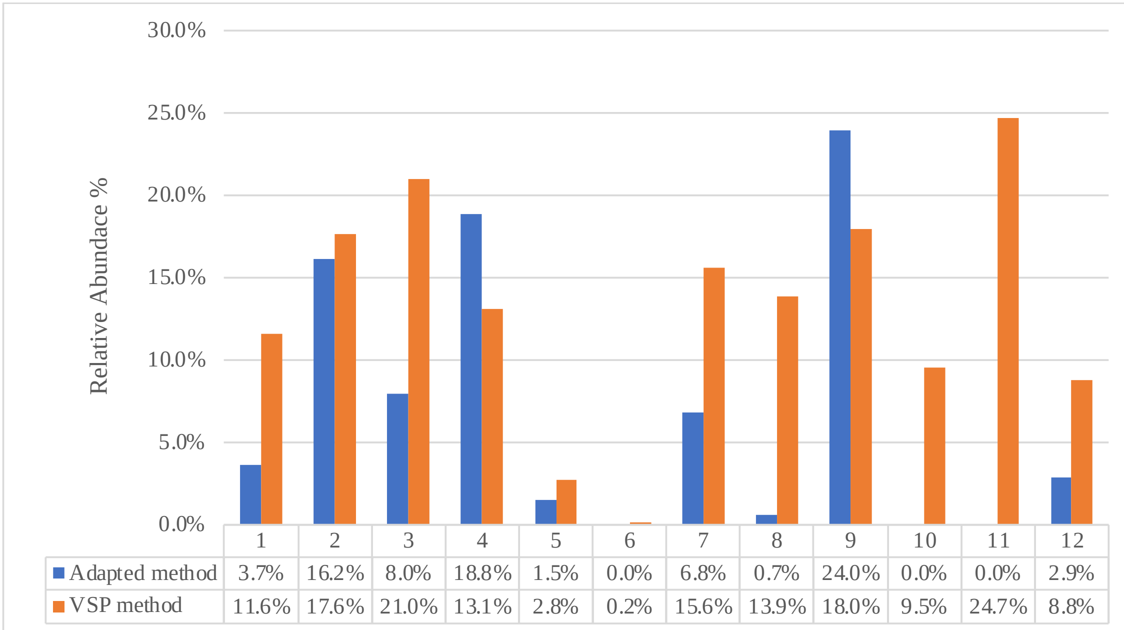


Figure 11. *The relative abundance of common buckthorn generated from the Adapted method vs. VSP method*

6. Discussion

6.1 The survey methodology

From the results, the adapted method provided a relatively weak numerical reference for species richness index and Exponential Shannon index, but the interpolation maps and species composition showed that this survey methodology could reduce the impact of losing small abundance species on biodiversity distribution by maintaining the sampling of high abundance species. Thus, in general, the adapted method is able to interpret and map the distribution patterns of plant diversity within the property and to use the associated data and images to study succession and evolution within the region to some extent. Due to the very limited and outdated status of biodiversity survey results within private woodlots and plantations in Southern Ontario, there is no way to compare the preliminary numerical outcomes from this project with the results of other sampling protocols and therefore it is difficult to conclude whether the adapted method has the ability to get a meaningful range of biodiversity index values; however, the significant difference in t-test ($p<0.05$) basically confirmed that the specific values obtained by the adapted method were less reliable compared to figures provided by VSP method under the same scenarios, even though they had similar distribution patterns of variation.

Briefly, the adapted protocol guarantees a rough estimate of biodiversity trends as well as species composition trends and is expected to detect and interpret different successional stages;

however, the protocol cannot make accurate predictions and interpretations for specific species abundance and distribution changes unless the abundance (i.e., plant cover %) of the species has reached a high level. Besides, due to the lack of documentation of historical forest management practices, this project is unable to interpret exactly how thinning interventions will affect plant diversity on the property at this stage, but it is still possible to infer potential historical activities on the property based on inventory data.

Manolaki et al. (2021) developed a similar methodology for rapid plant diversity pattern assessment, which also sampled only the smallest size sub-plot (i.e., 1 m^2), but required searching for additional species in larger sub-plots (10 m^2, 100 m^2) until the 1000 m^2 sampling area was completely explored. This methodology is also considered to be an informative and adaptable assessment tool, but its inventory speed is slow compared to the adapted method. Another similar method was used by Kalkhan et al. (2007) for rapid assessment. Again, intensive sampling occurred only in a 1 m^2 sub-plot but searching for additional species over a larger area (25 m^2, 225 m^2). The methodology has proven to be equally effective.

Thus, the question remains whether the sample size collected by the adapted method is the minimum standard, or it does not meet it.

6.2 The minimum requirements for data collection

For biodiversity monitoring and assessment, it is often assumed that more and more accurate data will reflect the more actual situation of the area. However, basically, non-professional surveyors prefer to sample in a rapid but relatively precise way to obtain a more valuable overview interpretation with less data.

Biodiversity is a changing scenario, and the interaction of external factors affecting diversity makes the process more unpredictable (Rossberg, 2013; Santini et al., 2017) A range of indices behave differently under different conditions, making it challenging to define a minimum data requirement threshold. According to Santini et al. (2017) for better adaptation to different scenarios and to capture signals of biodiversity change at an early stage, the main sampling data should include species composition and species abundance to be applicable for the calculation of various useful indices, which is also confirmed by Stohlgren et al. (1997) and Kalkhan et al. that the presence or absence of a species and the species cover (which will be converted to abundance) are essential to obtain meaningful data necessary to obtain meaningful biodiversity patterns.

Both sets of data were similarly collected in this project. However, considering that sample size is another factor affecting biodiversity indices, a determination of the minimum sampling area is also needed. Smaller sampling would loss information; this is critical for protocol development, that is, what kind of information can be skipped. It is a common fact that species diversity and the amount of information it brings increases with larger sampling area, but smaller plot sizes may not provide sufficiently valid information (Hopkins, 1957; Klimeš et al., 2001; Hoffmann et al., 2019). However, the definition of its exact size has not been determined yet. Given the adapted method developed by this project only intensively sampled 4 m^2 area, which is 1/100 for the plot size, it might be necessary to increase the area to get more information.

7. Recommendations

7.1 The suggested sampling plots number

Many studies for plant diversity assessment have recommended the establishment of larger sampling areas and more sampling plots; however, since private woodlots in Southern Ontario are typically small in size and could be homogeneous due to landowner interest and land use practices, and more. Therefore, it is recommended that the number of plots established will be based on property size and woodlot character. Typically, the number of sampling plots is considered to be determined by the number of ha within a small property, for example, 1 plot per ha; if private woodlots demonstrate homogeneity, it is acceptable to reduce the total number of sampling plots given the time constraints. However, it is important to ensure that three and more sampling plots are established; these plots are randomly selected, but ideally should represent the edge, center, and in-between of the stand to adequately reflect the distribution patterns of plant diversity.

7.2 Plant diversity monitoring implementation

There are various preparations that need to be made before this monitoring protocol can be formally implemented.

It is obvious that this adapted protocol is still in the theoretical stage; its application and validity have not been fully proven. The details of the specific protocols and survey methodology still need further modification. The key to designing an effective monitoring protocol is to be precise about the objectives, that is, what is needed from the survey and how the survey data will be applied to inform on-going monitoring. Any possible deviation will significantly compromise the information obtained from the sampling. The author may have missed some considerations when designing the methodology in the absence of more explicit and specific objectives for private woodlots biodiversity and the demands of landowners for monitoring programs and sampling methods. Therefore, certain forms of surveys, such as questionnaires and interviews, would be needed before the protocol is officially implemented, to understand who will be involved in the monitoring program, as well as their educational background, abilities and interests, and what results they expect to see, on what spatial and temporal scales. The results of the survey, as specific as possible, will be returned for use in targeted modifications to the adaptation protocol.

In addition, activities like demonstrations, field days or workshops will help increase landowners' awareness and acceptance of the biodiversity monitoring program (Meadows et al., 2014). Direct communication will help the OWA understand what potential barriers still exist to the pilot projects, for example, low returns due to long timelines, while also helping landowners to understand what they should do, how to do it, and who will provide them with resources and technical support. Most small private woodlot owners will need professional advice and access to other resources they need (Meadows et al., 2014).

7.3 The monitoring schedule

Returning to the monitoring program itself, once the protocol is officially implemented, schedule will need to be developed for ongoing evaluation. The first inventory should be conducted before the first thinning to gain a baseline description of the species within the property, focusing on species composition. Following sampling surveys will be conducted after the thinning but avoiding the same or following year if the operation occurs in winter to allow time for species to respond to habitat changes. The understory vegetation will use this period to re-establish; some species will spread from adjacent areas. Considering that the interval between each thinning is usually 10 to 15 years, at least one survey should be conducted during the gap. If the landowner is interested, a survey can be conducted immediately to examine the short-term effects of forestry management operations on the habitat within a relatively short time period after the thinning. It is worth noting that this special case requires at least one additional survey, in the following few years, to ensure that estimates of overall trends are relatively accurate.

Monitoring of plant diversity is often associated with phenology. Briefly, sampling should be done concentrating on the growing seasons, especially when most plants are flowering or just after the blooming phase (Stohlgren, 2007). Early spring and late fall frosts should be avoided; a cold season would allow most herbaceous plants die and get an unexpectable result.

8. Conclusion

The adapted protocol developed from the vegetation sampling protocol has the ability to make rough estimates of plant diversity in small private woodlots in Southern Ontario and to infer biodiversity distribution patterns, while not providing accurate species-specific abundance and distribution maps. However, due to the very limited simple size, the diversity index values obtained by this method are not statistically reliable. Through this project, it can be determined that the minimum data collection should include information related to species composition and species abundance, but the minimum working area that can provide valuable insights has not been determined. In addition to this, this project did not examine the specific effects of thinning on plant diversity due to the lack of available data.

It is expected that more private woodlots with different sizes and management practices will be tested in the next stage, and appropriate modifications will be made based on the feedback. However, there might not be a good way to balance data accuracy and time-money costs, as there is also a lack of information about how much time and dollars surveyors are willing to spend, at what frequency they conduct field surveys, and what results they hope to receive.

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Appendices

Criteria	Evaluation						
	Species Richness	Exponential Shannon	Shannon	Pielou Evenness	Simpson	Berger-Parker dominance	PIE
Easy quantification	3	2	2	1	3	3	1
Easy intrepretation	3	3	2	1	3	1	2
Sensitivity	2	3	2	2	1	2	2
Small sample size	1	2	2	2	1	1	3
Widespread utility	3	2	3	1	3	2	2
Total	12	12	11	7	11	9	10

Table 1b. Evaluation of various biodiversity indices based on specific criteria.

1 = not applicable, 3 = applicable

PIE: *Probability of interspecific encounter, which assumes that each individual can encounter/interact with every other individual in a given area, but that assumption would not hold true in reality. (Hurlbert, 1971)*

Evaluation framework

- Easy quantification
  - Applicable

    It is easy for people, especially those without relevant backgrounds, to calculate the index and get numerical results.
  - Not applicable

    People cannot easily to calculate the index or get numerical results.
- Easy interpretation
  - Applicable

    It is easy for people, especially those without relevant backgrounds, to understand and interpret numerical results.

    It is also easy to capture the changing pattern/trend.
  - Not applicable

    It is not easy for people to interpret results or capture the trend.
- Sensitivity
  - Applicable

    Numerical results are easily influenced by independent variables (environmental changes) and respond quickly to signals of biodiversity change at the early stage.
  - Not applicable

    Numerical results are not easily influenced by minor changes in independent variables and respond slowly to biodiversity unless the change is significant.

- Small sample size
    - Applicable

    It is not easily influenced by sample size and/or sampling efforts
    - Not applicable

    It is strongly influenced by sample size and/or sampling efforts.
- Widespread utility
    - Applicable

    There is a large amount of available material for meaningful research using this index.

    The flaw is acceptable or there are already extensive modification parameters.
    - Not applicable

    There are few available materials for meaningful research using this index.

    The range of application and flaws are still unknown.

Plot #	PlotGPSnum	EASTING	NORTHING
1	93576	620186.1310	4888803.9822
2	92745	620585.5230	4889004.7833
3	91993	620523.9096	4888926.8930
4	91988	620382.9849	4888905.1470
5	91985	620327.4575	4888822.7079
6	78921	620047.0984	4888788.5408
7	77867	620666.0729	4888942.4633
8	77169	620608.8753	4888862.9210
9	77168	620466.7042	4888843.2028
10	59938	620229.3081	4888903.7417
11	59936	620117.4898	4888858.0563
12	48713	619987.3097	4888701.6344

Table 3. *The plot number, its corresponding GPS number, and geographical coordinates*