CITIZEN SCIENCE:
THEORY AND PRACTICE

Practical Activities Promoting Engagement in Forest Ecology Research

RESEARCH PAPER

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ABSTRACT

Improving public engagement in ecological research improves the visibility of science and educates a wider audience about the value of ecology and its study. To this end, we assess the success of two simple activities, designed to track forest cover and understorey conditions, implemented at Lammi Biological Station Science Trail, Finland, in terms of effective public participation and useability of the data generated. We consider how best to engage participants in the activities, and we validate the data obtained by comparison of its reliability and useability against standard ecological approaches. It is also increasingly timely for researchers to utilise the large datasets that can be generated through effective public engagement. If experiments are effectively designed, these data can provide information at a larger scale than is attainable with the resources typically available to individual research projects. Consequently, given high enough uptake, such activities hold the potential for upscaling or generalisation from their findings. Both activities proved useful to collect more intensive data than would otherwise have been feasible. The quadrat vegetation survey (Activity 1) provided useable data to determine species phenology but not species composition. The canopy disk observations (Activity 2) reliably tracked seasonal changes in canopy cover when calibrated against baseline data. Training in these activities fostered engagement in how climate change affects forest ecology, improving the quality of data collected, and engaging participants eager to learn about and contribute to research into these processes.

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INTRODUCTION

Citizen science activities in general aim to combine education, engagement, and utility for research. The underlying goal of such scientific activities, with respect to the public, is to enhance education about what scientific research entails, while at the same time improving perception of its value (Shirk et al. 2012). Giving people firsthand experience of research activities and their context should also improve the public's understanding of scientists' motivation, making science less remote, with the added benefit of increasing the knowledge of science (in this case ecology) across society (Miller-Rushing et al. 2012). Additionally, improving the connections between the public and scientific research also fulfils the imperative for scientists to show how the funding they receive for research is spent, as well as potentially attracting some participants into science as a career (Silvertown 2009).

Data collection in plant ecology usually relies on repeated observations in nature. Often, basic training can give the observer those skills required to collect ecological information with reasonable accuracy, but low replication of observations limits the inferences that can be drawn from small datasets (Mouquet et al. 2015). Hence, data collected by multiple non-experts, over a time period or geographical range extended beyond the capacity of a single research project, may be utilised by researchers in ecology taking a broader perspective (Bonney et al. 2009). This approach has recently been gaining popularity through citizen science, which encourages wide participation in data collection by members of the public and is one way to obtain large datasets ("big data"), which may be of uneven quality (Hampton et al. 2013). While data collection is often straightforward, expert ecological knowledge is usually required to identify the most pertinent and novel questions to ask about an ecosystem and to estimate the breadth of observations needed to put collected data into a useable context. Hence, citizen science projects usually require coordination by ecological researchers with appropriate background knowledge and expertise.

Recordings of plant phenology, that is, "the seasonal development of plants through the phases of their life cycle," exemplify the type of data that lend themselves to collection through this approach. Many people find tracking seasonal changes engaging, and once the observer is trained to recognise the different stages of a plant's life cycle, it is often quick and easy for them to collect phenological data. The larger the database of phenology observations, the greater its value; that is, many observations covering many scenarios over an extended period of time allow the most (ecological) information to be extracted. In this way, our ability to match plant ecological data with environmental parameters can be enhanced by relating findings to site-specific habitat, weather, or climate information, which are widely available (Miller-Rushing et al. 2019).

In this article, we aim to test the success of two activities associated with the research of the Canopy Spectral Ecology and Ecophysiology (CanSEE) group at the University of Helsinki in terms of effective public participation and useability of the data generated. We designed and implemented both activities on the Science Trail at Lammi Biological Station of the University of Helsinki. In this context, we consider how best to engage participants, and we validate the data obtained by comparison of its reliability and useability against standard ecological approaches. Activity 1 involved a survey of the understorey plant community and its phenology at two locations differing in their canopy cover. The timing of development of understorey plants depends on their location and on the type of forest they inhabit, and varies according to the weather each year. Monitoring their development tells us how the light conditions and habitat created by different canopy trees modify the plant community on the forest floor (Kudo et al. 2008). Long-term and detailed records of phenological development can also be useful in understanding climate-change effects on phenology (Primack and Miller-Rushing 2012, Tang et al. 2016). Activity 2 involved a basic survey of canopy closure and assessment of phenology in a *Betula* stand. Data were collected from participants in both activities over a period of more than 12 months during 2016 and 2017.

When we as researchers characterise microclimatic conditions in the forest, changes in the amount of light reaching the ground through the year are one of our most important considerations. These changes can be approximated using a "leaf area index" (LAI): This tells us how many gaps in the canopy there are through which we can see the sky, compared with the leaves, trunks, and stems blocking our view of it (Zhang et al. 2005). Through the year, we can look to associate changes in the amount of sunlight reaching the ground with differences among those plants we see growing on the forest floor (Kudo et al. 2008). Thus, the results of both activities could be directly compared with the equivalent research undertaken by the CanSEE group at the site, allowing their reliability and research value to be assessed. We also assessed the quality of data obtained from different groups of participants, as a metric of their level of engagement. Differences in the relative effectiveness of task performance indicated what improvements might be needed before the tasks can be upscaled.

METHODS

ACTIVITY 1: COMPOSITION AND PHENOLOGY OF THE UNDERSTOREY PLANT COMMUNITY

Wooden quadrats (50 cm X 50 cm) were placed at fixed locations in the understorey of forest stands alongside the Lammi Biological Station Science Trail (central-southern Finland, 61°3.24N 25°2.23E, 155 m asl), in places where the plant community is composed of several key understorey species that are widespread, seasonally dynamic, and archetypal of shaded forest habitats. A grid within the quadrats was formed by string at 10-cm intervals, meaning that each quadrat contained 25 10 cm x 10 cm squares. A notebook/data-sheet with a table to fill out and an identification panel were provided at each location (Supplemental File 1: Appendix A: Supplemental Figure 1), illustrating and describing the designated plant species, to allow the participants to correctly identify the species in the quadrats. The worksheet listed the type of observations for each visitor to make, which were based on simply counting the number of plants, leaves, and flowers inside each quadrat on a given day. The worksheet also contained a box for the date, time, and weather (e.g., sunny, overcast, raining, snowing), as well as a place for the observer's name, plus questions related to biodiversity of the plot in general, and the abundance and phenology stage of individual species. Photos of the focal species, *Oxalis acetosella* L., *Fragaria vesca* L., and *Hepatica nobilis* L., were provided (Supplemental File 1: Appendix A: methods, sample form, and a description of the species' natural history).

Connection to research and validation of Activity 1

In the CanSEE research group, we are studying the environmental factors that influence the timing of phenology in canopy trees and understorey plants, and how the interaction between the two may change under different conditions (Brelsford et al. 2019; Brelsford and Robson 2018; Hartikainen et al 2020). Canopy trees influence not only the amount of light reaching the forest floor but also the spectral composition of that light (Federer and Tanner 1966; Vézina and Boulter 1966). Leaves absorb most red light but reflect far-red light: This leads to an impoverished red:far-red ratio in the forest understorey, something that plants can detect as signals of potential competitors for sunlight (Legris et al. 2017). It is expected, following similar logic, that the ratio of blue:green sunlight and UV:visible sunlight could also provide signals for understorey plants. These signals should change with different canopy tree species and with time of day and time of year (Hartikainen et al. 2018).

The composition and timing of development of the understorey plant community is indicative of the differing conditions found across different forest types. It is important for the fitness of these plants that they coordinate their development with pollinators and dispersers, as well as with canopy trees, to attain enough light for photosynthesis (Kudo et al. 2008). Not only would we expect the timing of growth of these understorey flowers to be adjusted to suit their environment, but also their flower size and colour should match the light available in the forest so that they are visible to pollinators, and produce nectar and pollen at the right times.

Trends in the abundance and phenology of *Oxalis*, *Hepatica*, and *Fragaria* growing in the two stands, visible from citizen science (CS) data, were compared with data from a comprehensive survey of understorey species in the same stands during the spring and summer 2016 (Pieristè, data unpublished elsewhere). These data were collected within a radius of 3 m around four measuring points in each of the two stands, and the density of plants per square metre was calculated.

ACTIVITY 2: HOW MUCH LIGHT REACHES THE GROUND?

A set of identical wooden disks with holes drilled through them were kept in a waterproof box at each station on the trail, where participants could pick them up, together with activity sheets containing a short explanation of the activity (Supplemental File 1: Appendix B: Supplemental Figure 3). Disks had about the diameter of a saucer and the design was inspired by Brown et al. 2000 who suggested the disk be made of solid, rigid, not bendy/breakable material. We used wood because it has the advantage of being more tactile and was consequently preferred by the participants, and it is cheaper than metal. We placed at least one station in each forest stand type to allow a comparison of canopy closure of different tree species.

The participants look vertically up through the disk, with their eye at a set distance from it. To solve the problem of always maintaining the same distance, we fixed a string of 20 cm on one corner of the disk, at the base. To inspect the forest canopy, participants were instructed to hold the end of the string in one hand next to their eye, while keeping the string taught by holding the corner of the disk next to the other end of the string with their other hand (Figure 1*b*). By standardising the distance between the eye and the disk, any error due to the amount of the canopy seen through the disk was minimised.

The principle behind Activity 2 is to facilitate an easy way to estimate the amount of light penetrating the canopy. This is achieved by dividing the disk into sectors (12, like

Figure 1 (a) Some participants doing Activity 1 at the location of the quadrate vegetation survey. Photo by TC La Brijn. **(b)** Matthew Robson demonstrating the canopy observation activity (Activity 2) in front of the information board. Photo by SM Hartikainen.

a clock face), each of which are split transversely in half, making 24 sectors of equal size. The participant counts, and notes down, how many of these sectors are predominantly light and dark, keeping the disk still as they do so (Figure 2). The instructions also are available to the participants as a video (https://youtu.be/M78RrsoIK8o). In practice, it is easier, cheaper, and more effective to have a disk that is solid, apart from 25 small holes of equal size (i.e., 10 mm diameter drilled through the disk), rather than one that is entirely transparent. One hole was drilled in the middle of each of the 24 sectors, so that the holes are equally spaced, plus one through the centre of the disk.

To perform the activity, participants were instructed to look up at the canopy and count the number of holes through which they could see only sky, versus the number of holes with only forest canopy made up of leaves, and the number of holes with only tree trunks and large branches. Those holes containing a roughly even mixture of these elements required a degree of subjectivity to allocate into categories. To reduce this subjectivity, the participants were asked to rotate the disk to obtain the most holes with only sky that they could see from one place. Likewise, it was necessary to control for the angle to the sky at which the disk was held, because looking vertically up gives a much shorter path-length of light through the canopy than looking towards the horizon, so would affect the values obtained. To avoid this type of error, each participant to was instructed to take one measurement looking vertically through the canopy (this will give the maximum sky and minimum trunks), and then four measurements: at 45°, at halfway between the horizon, and the vertical measurement at right angles from each other in each cardinal direction (the equivalent of facing towards each compass point).

To complete the activity, the bud development stage of the canopy trees should be estimated, allowing a connection to be made between LAI and tree phenology.

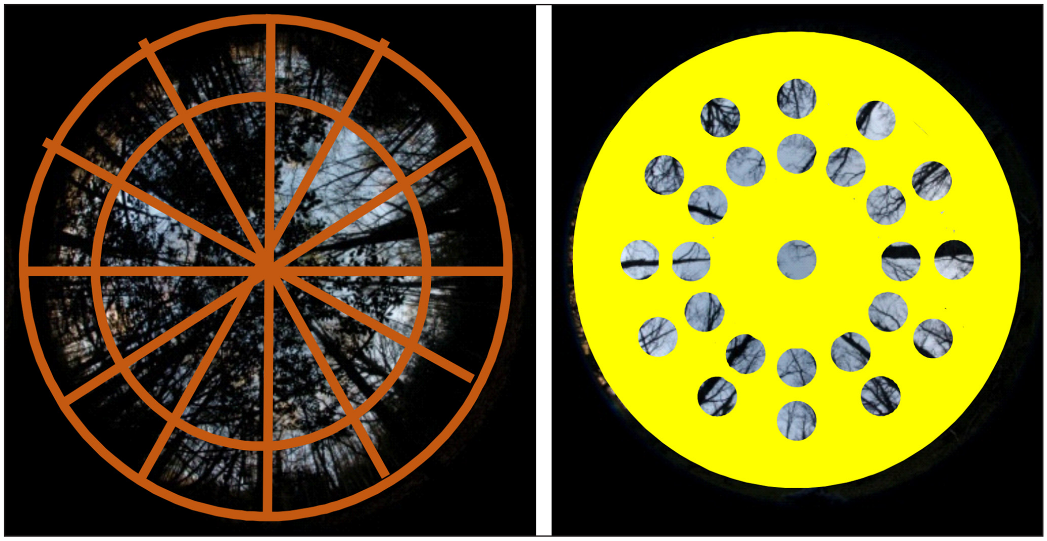

Figure 2 Development of the design of the canopy observation disk shows (*left*) 24 transparent sectors in the canopy projection, and (*right*) an arrangement of 25 holes of 10-mm diameter cut through a solid wooden panel with a drill.

At each station, sketches or a scale using photographs were given for the phenology of the principal canopy trees: birch, poplar, oak, and cherry, and the participants wrote down which developmental stage most of the tree buds had attained (Figure 3).

Connection to research and validation of Activity 2

An estimation of forest canopy closure provides information on bud burst and flushing that can later be compared with changes in the spectral composition of sunlight reaching the forest floor as measured by spectroradiometer as part of CanSEE Group's research (Hartikainen et al. 2018, Hartikainen et al. 2020). The way in which different canopy species develop in the spring reflects differences in their mechanisms of detecting and responding to environmental factors such as temperature, day length, and spectral quality (Augspurger and Salk 2017). By combining these flushing data with weather data, we can create process-based models of the dependence of spring phenology on different aspects of the environment. These models should eventually be good enough to forecast when trees will come into leaf under future climate conditions in different locations. By monitoring the change in LAI and composition of sunlight in several sites across a wide geographic range, we hope to unify the models for each driving factor and tree species.

The utility and replicability of the assessment of canopy closure and phenology was compared against hemispherical photos. Canopy disk data from four measurement points in each of five stands differing in their canopy composition (mature *Acer platanoides* L., *Betula pendula* Roth., *Populus nigra* L., *Picea abies* (L.) H. Karst., and young [10-year-old] *B. pendula*) were collected on 21st July 2017. To compare these data with LAI data from hemispherical photos taken at these measurement points, an estimate of the proportion of cover was made using the proportion of open (0.0) and closed/covered (1.0) holes in each category. Holes were allocated to categories titled "trunks," "leaves," "mixed," and "sky:" "Trunks" were considered 1.0 cover, "leaves" were considered 1.0 cover during spring-summer and 0.25 during winter (assuming some part twig), "mixed" were considered 0.5 cover for spring-summer and 0.25 for winter (assuming some part leaf and twig), and "sky" were considered 0.0 cover all year round. LAIs from hemispherical photos were compared with the composite LAI obtained by combining vertical and horizontal canopy-disk readings and with only vertical or only horizontal readings in isolation.

DATA ANALYSIS

The datasheets from the two activities were categorised into groups based on their intelligibility as either: incomplete/entirely-nonsensical data, partially complete/intelligible data, or complete/intelligible data. Assessment of the quality of data was based on entries falling within the range of feasible results, and on, for example, proportional data needed to sum 1.0. The fraction of entirely nonsensical data was noted and omitted from the subsequent analyses.

For Activity 1, observations from consecutive days were averaged together when there was only one survey per day. These data were compared with wider surveys by researchers of understorey plant development in the two stands. The results of Activity 2 were compared to calculations of LAI made from hemispherical photos of the

Figure 3 Key to the stages of *Betula* sp. (birch) spring phenology. These seven images show the progression of canopy flushing (bud burst and leaf unfolding). Redrawn using Kubin et al. (2007) as a template.

site before, during, and after the period of canopy closure, and senescence in the autumn, to assess the consistency of the two approaches. These LAI data were collected by researchers in the CanSEE group as part of a broader research project (Hartikainen et al. 2020).

RESULTS

ACTIVITY 1: COMPOSITION AND PHENOLOGY OF THE UNDERSTOREY PLANT COMMUNITY

Participation in the activity

The understorey plants were monitored by visitors to the Biological Station, where students and school groups engaged in the activity on 68 occasions between the two quadrats. All those datapoints from the same or consequative days were pooled, leaving 22 averaged records retained for analysis on different dates during the periods August–September 2016 and May–June 2017. Most data could be used as entered, but entries that were obviously erroneous were amended when species had been misidentified or the abundance over-estimated beyond the upper limits of the number of squares in the quadrat.

Validation of the approach through comparison with our research survey

In all three of the studied species the timing of phenological events, the production of new leaves and flowers, and the stolons from *Fragaria* were consistent with the data collected by researchers from deciduous stands (Table 1). While there was greater variability in the data from participants in the activities, more frequent sampling and higher replication allowed more detailed trends to be plotted (Supplemental Fie 2: Understorey Activity Data and Graphs and Supplemetal File 3: Understorey Activity Data and Graphs (CS). In contrast, data on the occurrence and density of cover by different species in the oak stand produced from the activities did not correlate well with the researchers' survey. Neither linear regressions of cover of *Oxalis* (r = 0.08) nor *Hepatica* (r = –0.42) were significant, but trends in *Fragaria* cover (r = 0.80; $y = 3.92x + 2.6$) over the spring were well matched.

Patterns in understorey growth and phenology

Differences between performance of the three species in the spruce and oak stands were visible in the results of the activity summarised in Table 1 and provided in full in the supplemental material**.** Seasonal patterns in folding and unfolding of *Oxalis* leaves were recorded, with more unfolded leaves in the spruce than in the oak stand, and leaves were folded more often in early spring prior to spring canpy flush and on sunny days when sunflecks reached the forest floor (Table 1). *Fragaria* was the only species to favour the oak stand, producing stolons throughout the summer there, but only during autumn in the spruce stand (Table 1). *Hepatica* plants produced a second annual cohort of leaves only in the spruce stand, which contributed to their greater cover under spruce (4–8 leaves) than in the oak stand (2–6 leaves) (Table 1).

Considering trends in density of the three most common understorey species in quadrats in the oak and spruce stands (Figure 4), *Oxalis* produced new leaves in the spring of 2017 in both stands (Figure 4*a*) but it was present at far greater density in the spruce stand. It was possible to identify differences in the phenology of winter leaves in *Fragaria*, which started to grow about 5 days earlier in the spruce (year-month-day: 2016-09-26) than in the oak stand (2016-10-01) (Figure 4*b*). It was not possible to distinguish summer 2016 trends in *Hepatica* growth, but

SPECIES	TRAIT	SPRUCE STAND	OAK STAND	DECIDUOUS STAND
Overall	Number of species	3–5 species Decline starting 2016-08-28	4–6 species Spring ephemerals 2017-05-01 to 2017-08-06	NA
	Cover	Increasing from 55% to 100%, 2017-05-01 to 2017-05-10	Spring 60%, autumn 20%	NA
Oxalis acetosella	Cover	100% cover throughout	Increasing from 10% to 50% 2017-05-01 to 2017-08-06	Increasing to 25% by 2016-07-02
	Unfolded leaves	100% apart from sunny days 2016-08-23 and 2016-08-25 (80%)	Variable % from 2016-to-09-08, but always lower than spruce stand Spring 2017, 10% initially, rising to 70%.	> 80% from 2016-05-17to 2016-06-18. Spring 2016, < % 80
	New leaves	Summer cohort starting 2016-08-25 Spring cohort starting 2017-05-15	Timing as spruce stand, but fewer leaves	Spring cohort starting 2016-05-11
	Flowers/ seeds	Flowers 2017-05-06 to 2017-06-06 Seed pods from 2016-08-30	No flowers recorded Seed pods from 2016-09-26	Flowers 2016-06-05 to 2016-05-11
Fragaria vesca	Cover	10–20% in spring 2017 20–100% in summer 2016	30–40% in spring 2017 As spruce 20–100% in summer 2016	Increasing from 5% to 10% in spring 2016
	New stolons	From 2016-09-01 onwards in autumn only	From 2017-05-30 onwards through summer	From 2016-06-07
	Senescent leaves	2017-05-27 and 2017-05-28 in spring	2017-05-30 in spring	NA
	Flowers/ fruits	Starting 2017-05-28	Starting 2017-05-27	Flowers 2016-05-28 Fruiting 2016-06-02
Hepatica nobilis	Cover	4–8 leaves per m^2	2–6 leaves per m^2	~20% presence in quadrats
	New leaves	Spring cohort 2017-05-01 to 2017-05-25 Winter leaves from 2016-08-24	Spring cohort 2017-05-01 to 2017-05-15 No winter leaves	Spring cohort: 2016-05-05 to 2016-05-17
	Senescent leaves	~50% of leaves from 2017-05-28	~50% of leaves from 2017-05-01	NA
	Flowers	From 2017-05-01	No flowers	From 2016-04-25

Table 1 Results of the vegetation survey activity on the main understorey species from quadrats in spruce and oak stands, and from researcher-collected data at the deciduous stand level. Full data are given and presented graphically in the supplemental material.

in spring 2017 (2017-05-27), their over-wintered leaves started to senesce (decline in number) in the spruce stand (Figure 4*c*). *Hepatica* both produces new leaves and loses leaves to senescence in spring, and together with its relatively low cover, this likely confounded any relationship between the two datasets.

ACTIVITY 2: HOW MUCH LIGHT REACHES THE GROUND?

Participation in the activity

In total, the activity was completed 143 times over 50 different days between 2016-06-07 and 2017-06-24. Since multiple school and university groups passed along the trail during this period, Figure 5 includes several days when many individuals completed the activities at the same time. Of the 143 datasheets completed, 18 were adjudged incomplete/nonsensical datasheets (omitted from analysis), 41 were partially complete/intelligible datasheets, and 85 were complete/intelligible datasheets (the latter two sets were included in the analysis). From these data, we calculated daily averages, or averages over a period of observations on 2 to 3 consecutive or nearby dates (15 cases); where datasheets were only partially intelligible, these data were averaged over a period of several days. In total, this gave 24 time-points with measurements of canopy closure, each time-point being a mean average of between 2 and 17 datasheets (the median number was 4 datasheets). Our feedback suggested that some participants struggled to exercise the subjectivity required to choose which category to put the canopy into (i.e., to determine when a mixture of branches and sky was visible through the holes versus only leaves, or only branches, or only sky. The instruction

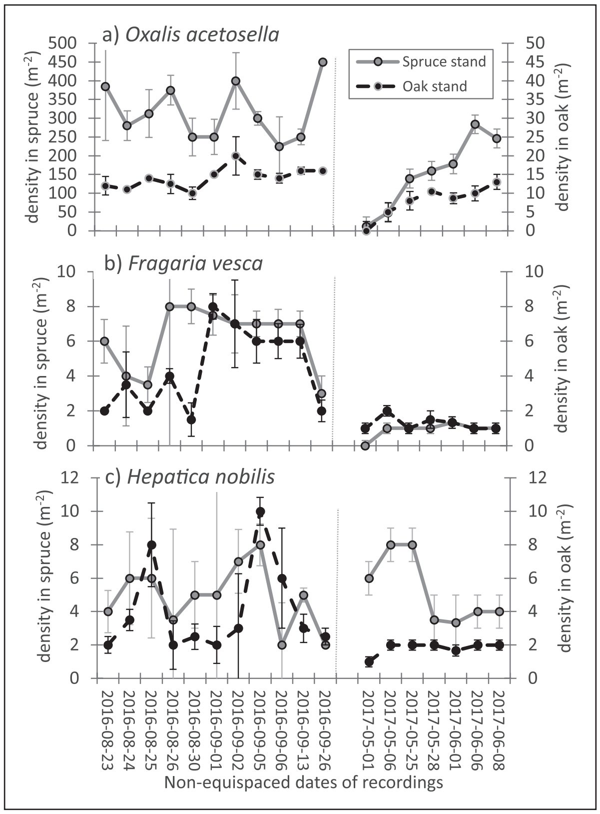

Figure 4 Plot showing a time series of changes in understorey plant cover of three common species, **(a)** *Oxalis acetosella*, **(b)** *Hepatica nobilis*, and **(c)** *Fragaria vesca*), over one year in spruce and oak stand. Data are median ± 1 SE for each set of recordings. Non-equispaced dates of recordings are given on the x-axis, and a grey vertical dotted line marks the start of the winter period under snow when no recordings were possible. Note that *Oxalis* in the oak stand are plotted on a secondary axis at a far smaller scale for ease of comparison of the trends. Raw data given in the Supplemental Files 2 and 3.

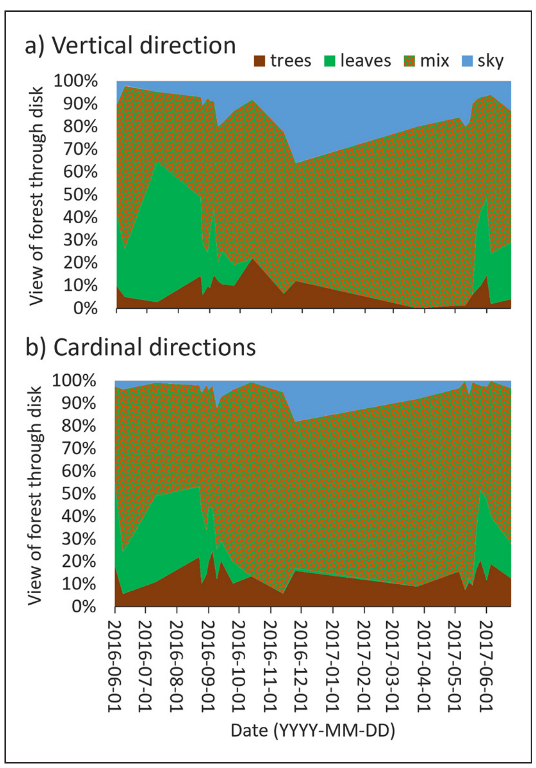

Figure 5 The percentage composition of the canopy viewed through the canopy disk. One year of measurements, twenty-four occasions, at the same location in a *Betula* sp. stand on Lammi Biological Station Science Trail. **(a)** Vertical observations looking directly up through the canopy, and **(b)** "horizontal" cardinal observations, looking at a 45° angle above the horizon in each of the four cardinal directions.

to rotate the disk to obtain the maximum number of holes with only sky was added to help overcome this problem.

Validation of the approach through controlled tests in multiple sites

Vertical, horizontal, and combined canopy disk data all gave strong positive correlations against summer LAI, but the closest relationship was obtained by weighting vertical and average horizontal readings equally at each measurement point ($R^2 = 0.54$; Figure 6*a*). Comparing the non-leaf canopy disk readings with LAI calculated from photos taken during the winter did not yield a meaningful correlation among deciduous stands. The inclusion of data from the evergreen *Picea abies* stand did produce a highly significant overall R^2 but this was only because of the very large difference in LAI between evergreen and deciduous canopies ($R^2 = 0.92$; Figure 6*b*). The slope of this relationship (5.48) was at least similar between the summer and winter (Figure 6), allowing the relationship to be used as a conversion factor from canopy disks to estimate the LAI using our nature trail data.

Patterns in canopy closure compared with hemispherical photo data

The results cover only one full year in the forest stand from June 2016, when spring flush was already almost complete (phenology stage 7), up to the completion of spring canopy flush in June 2017. This allowed us to follow a trend in canopy openness and closure through the autumn and spring seasons (Figure 7). As expected, the vertical observation allowed more sky to be seen than the horizontal observations, so by employing both orientations, participants could capture more of the variability in canopy openness at different times of year.

When the annual cycles in LAI in the understorey of the *Betula* stand at Lammi Biological Station are compared using hemispherical photos and the canopy disk method, with LAI calculated using the calibration from Figure 6*a*, the relative effectiveness of the methods can be assessed (Figure 7). Some errors or inconsistencies in the canopy disk method are apparent during the transitions through bud burst and autumn leaf fall, but in general the timing of these changes are in agreement between the two

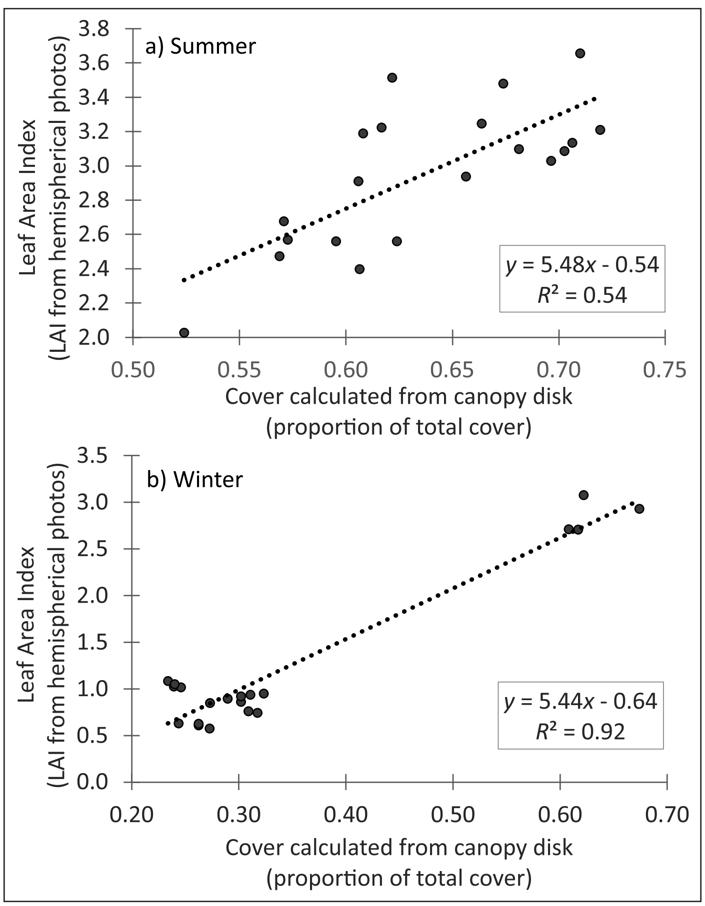

Figure 6 Calibration of the canopy disk through comparison of canopy cover calculated from the mean of the vertical and cardinal measurements against the leaf area index (LAI) calculated from hemispherical photographs (according to Hartikainen et al. 2018). Parallel measurements with the two approaches taken from four measurement points in five different forest stands in Viikki Arboretum, Helsinki, in **(a)** summer and **(b)** winter.

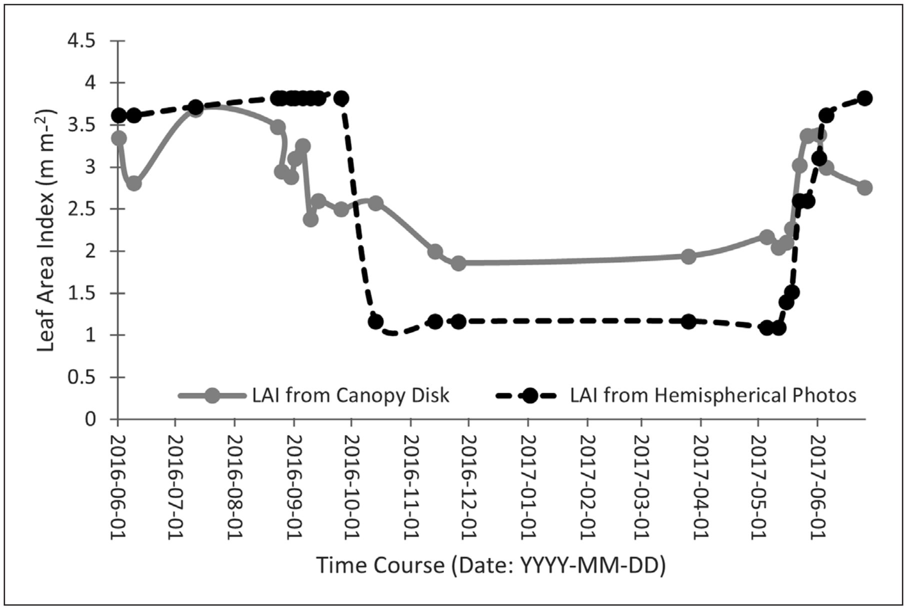

Figure 7 Leaf Area Index (LAI) in the *Betula* sp. stand at Lammi Biological Station over the one-year period, calculated from data collected through the canopy disk activity compared with LAI calculated from hemispherical photographs.

techniques. The canopy disk approach is able to capture some of the fine-scale variability in the time course that might not otherwise be visible (Figure 7). In winter, the canopy disk method gave a higher estimate of LAI than our hemispherical photos. This may be because of the weight given to the "mixed" category in winter or because of viewing some ground through the disks. This weighting could be lowered to improve the match to hemispherical photos data, but given that there is also subjectivity in selecting the exposure of the photos, improving the match doesn't necessarily give a truer result. This most important consideration is to use consistent criteria in the assessment among stands and measurements to enable them to be compared.

DISCUSSION

PARTICIPATION IN THE ACTIVITIES, AND THEIR EDUCATIONAL VALUE

The Lammi Biological Station Science Trail was originally designed to activate visitors and to promote learning through a participatory approach. In this way, the traditional passive learning approach common to nature trails, where subject matter is presented on interpretive signs, is augmented by tasks that activate learners. There is a great deal of evidence to suggest that active environments promote more effective learning (e.g., Freeman et al. 2014; Deslauriers et al. 2019) and help to narrow achievement gaps among learners (Theobald et al. 2020). By implementing citizen science–based activities on the trail, our aim was to engage learners in scientific fieldwork, helping them to better understand this aspect of the scientific process, while gaining specific knowledge about ecological processes, phenology, and taxonomy.

Since most participants identified themselves on the datasheets, we could determine that school children tended to collect data of better quality than older university or college students, probably due to a higher motivation or to supervision of the activity. Additionally, data collected from volunteers seemed more complete and accurate than data collected by those university students who had been asked to do the activity as part of their duties. This reenforces the suggestion that the level of enthusiam for the activity, and its perceived relevance, as explained directly to the participants, plays an important role in the reliability of the data. A similar conclusion was reached from a study of marine debris that found primary school students to be more effective citizen scientists than secondary school students, who lacked focus and motivation (van der Velde et al. 2017). There is also evidence from studies of citizen scientists feeding birds that young adults find ecological studies rewarding when their participation is time-effective (Martin and Greig 2019). Participants are more engaged when they feel that the results they produce will be of scientific values, as here in climate-change ecological research, and if there is a social or companiable aspect to the activity (Martin and Greig 2019). These factors may all have contributed to the better results that we obtained from younger groups of participants who received more training and interaction than older participants.

The quadrat vegetation survey (Activity 1) allowed the participants to learn to identify plants at different stages of their life cycle. Participants were encouraged to think about how the composition of the plant community depends on the canopy trees and to question which factors are most important for determining plant community assembly (e.g., effects of tree cover on light, on temperature, and on the leaf litter that is recycled into the soil). Activity 1 illustrates to participants how the time of year affects the diversity and condition of understorey vegetation, and how much this changes among sites. In comparison, the canopy observation (Activity 2) draws participants' attention to differences in the timing and effect of tree leaf-flush phenology over the spring, while also stimulating ideas about how and why light conditions vary among different types of forest. The two activities together provoke contemplation of the consequences of differences in sunlight and canopy cover for biodiversity under each canopy.

RELIABILITY OF THE DATA

The quadrat vegetation survey used in Activity 1 is a widely tested method in plant science for the estimation of vegetation cover and species composition (Floyd and Anderson 1987). According to our results, the estimates of growth rates and phenological stages, and their differences among stands by citizen scientists, matched our stand-wide assessments. These data were more consistent with researcher-collected data when using the median of observations rather than the mean, which was biased by outliers. Nevertheless, the trends were quite noisy, and it could be expected that with more participants their reliability would be improved. In contrast, we do not suggest the use of data collected in this way to estimate species composition and abundance as it is difficult to control for monitoring of an area of forest representative of the whole stand.

Participants sometimes had difficulty recognising the target species, especially in absence of their flowers. Additionally, a higher replication (i.e., more quadrats at different points along the trail) would be necessary to obtain more representative results in terms of species composition across a stand. In our activity, we decided to use only two quadrats (one per stand) to avoid making the activity too time-consuming or tedious for the participants. The issue of replication alternatively could be addressed by using larger quadrats, as suggested in previous studies (Archaux et al. 2007), instead of more quadrats. When we tested the activity, we identified locations to place the quadrats, ensuring that they contained all of the target species present inside the quadrat area. While this allowed the volunteers to observe all the species, it might also have biased the results, since quadrats should be placed randomly in the stand in a well-designed study to determine the species composition (Crocker and Tiver 1948; Evans and Love 1957). Nevertheless we favour fixed quadrats, as allowing quadrats to be placed at random by participants would add noise to the results and would require that participants wonder through the understorey, potentially trampling some species.

The canopy disk used in Activity 2 proved to be a valid method to estimate canopy cover and LAI, presenting a good correlation with the estimates calculated by the research group through hemispherical pictures. A similar approach was tested before, and successfully proved to be a simple and reliable method for the estimate of canopy cover (Brown et al. 2000). While several alternative techniques are available, the canopy disk is considerably cheaper, more easily replicable, and more straightforward to use than most of these (Černý et al. 2019; Russavage et al. 2021). While a certain subjectivity is required and could produce a bias, the high number of replications obtained through the involvement of citizen scientists would compensate for individual user subjectivity when all are pooled. Additionally, the simplicity of the method allows untrained volunteers, like families and passers-by, to participate in the activity.

POTENTIAL REFINEMENTS

The discrepancies discussed between the results of these citizen sciences activities and researchers' findings suggest that there is room for improvement in the instructions and protocols of both activities. Additionally, we might expect that trained volunteers should be able to collect better data as was previously shown in several studies (Feldman et al. 2018). Below, we discuss specific improvements for both activities.

A compromise is required to retain the participants' interest while achieving high replication. Ideally, to obtain well-replicated data in the quadrat vegetation survey, one station with two to four quadrats should be located at multiple points representing each different canopy type along a trail. However, individuals shouldn't feel under pressure to survey quadrats at all points. This would allow for a more varied sample that should be more representative of the composition of understorey species in a forest stand. Using this approach, the quadrats at different locations could accommodate some species in common and some that differ to be more representative of the stand as a whole; for example, *Oxalis* and *Hepatica* dominate the understorey of the evergreen stands, while deciduous/broadleaved stands, though typically more diverse, may contain *Fragaria* or *Oxalis* in the understory.

Recently, various devices for monitoring LAI, and mobile phone apps for canopy photography, have been developed, providing everyday alternatives to the canopy disk method

(Černý et al. 2019; Arietta 2022). Using a mobile phone app designed to create a hemispherical image from fixed permanent locations under several forest types has been shown to give good reproducibility (Arietta 2022). This is a functional approach, but lacks the pedagogical aspect of the canopy disk and is subject to the same difficulties in standardisation as traditional hemispherical photography (Ribas Costa et al. 2022; Russavage et al. 2021; Torresan et al. 2021). In comparison, our canopy observation activity provides a cheap, simple, and novel way to estimate the penetration of light to the understorey. A densitoimeter could be provided to use as an alternative approach (e.g., YouTube video, how to use a densitoimeter), although obtaining accurate estimates using densitoimeters is known to be challenging (Applegate 2000; Russavage et al. 2021).

CONCLUSIONS

We designed and tested two citizen science activities, considered the reliability of the data collected, and suggested potential improvements. Both activities allowed a larger amount of data to be collected than would otherwise have been available to the researchers. Associating these two activities together should help to answer questions on the effects of climate warming on the coordination of understorey development and canopy phenology. The research value of both activities could be enhanced using a training programme for participants to increase the quality of data collected and to re-enforce the research value of these data. We found that participants were better motivated to complete the activities when working in small groups, and this also produced better quality data. The quadrat vegetation survey (Activity 1) was better suited to obtain growth and phenology data than for species abundance or composition. The canopy observation (Activity 2) was well matched with data collected by the research group using hemispherical photography. While canopy photography using mobile phone apps may supplant our canopy disk to measure canopy openness, there are practical and educational advantages to the hands-on approach of our activities, which require that participants actively assess the canopy and understorey vegetation.

DATA ACCESSIBILITY STATEMENTS

The data produced in this study are available in the supplemental material.

SUPPLEMENTARY FILES

The supplementary file for this article can be found as follows:

- **Supplemental File 1.** Appendices A and B. DOI: https://doi.org/10.5334/cstp.455.s1
- **Supplemental File 2.** Understorey Activity Data and Graphs. DOI: https://doi.org/10.5334/cstp.455.s2
- **Supplemental File 3.** Understorey Activity Data and Graphs (CS). DOI: https://doi.org/10.5334/cstp.455.s3

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COMPETING INTERESTS

The authors have no competing interests to declare.

AUTHOR CONTRIBUTIONS

MP and TMR wrote the manuscript, collated and analysed the data, and designed the activities along with SMH, TKK, and AP. JL and AP actualised the activities. AGJ, JL, and TMR supervised the study, and all authors provided editorial input.

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