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ORIGINAL RESEARCH

"Ready! Set! Lichen!": a citizen-science campaign for lichens, against the odds of success

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Abstract

Citizen science has successfully contributed lichen records to air pollution assessments and for detecting biodiversity hotspots, while its potential to survey broad lichen distributions and trends in natural ecosystems is less clear. The main issue is whether non-professional observers would be willing to visit remote areas to record inconspicuous organisms. We launched a nationwide citizen science campaign "Ready! Set! Lichen!" in Estonia (Northern Europe) that focused on collecting digital photo-based data on lichen distributions comparatively on live trees in forests versus in cut-over sites. Altogether 1101 trees were surveyed by 362 participants. Of all observations, 86% were acceptable and revealed 86 species plus 33 morphospecies as identified by experts. For a test set of selected 12 common epiphytic species, the campaign expanded their known national distributions on average 13%, independently of their conspicuousness (thallus type). Our results indicated that a mass participation approach of citizen science: (i) can provide significant data to monitoring broad-scale population trends of common forest lichens, but the contributions remained small regarding (ii) the knowledge on rare and sparsely distributed habitat specialists and (iii) ecological factors behind the distributions (due to difficulties in keeping valid sampling design). We conclude that citizen-science projects on inconspicuous highly diverse taxon groups can contribute to conservation research if these projects are specifically designed for feasible goals, and we outline six main areas of application for lichen studies.

Keywords Biodiversity data · Epiphyte · Lichen monitoring · Photographic survey · Retention forestry

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Introduction

Biodiversity assessment for conservation purposes relies on rigorous data collection, which is often limited by time, funding or the availability of experts (Underwood et al. 2018). One possibility to support professional experts in large-scale data collection is to involve non-professional volunteers, which can be developed into methodologically valid 'citizen science'-based surveys (e.g., Dickinson et al. 2012; SEP 2013; Kullenberg and Kasperowski 2016; Pocock et al. 2017; Aavik et al. 2020). In addition to the obtained datasets and scientific outputs, such biodiversity science campaigns contribute to education of the participants (Bonney et al. 2009) and, more widely, to public environmental awareness (SEP 2013; Meschini et al. 2021) and willingness to engage in conservation action (Day et al. 2022).

Lichens – symbiotic organisms comprising fungi and microalgae (or cyanobacteria) – are well-known bioindicators but have received relatively little attention in terms of citizen science. Thus far lichens have been included in 'mass participation' projects (easy participation by anyone anywhere, like the BioBlitz) or, after training, in targeted monitoring actions at given locations (Will-Wolf 2002). It has been most popular to involve volunteers to document the response of lichens to air pollution. Examples include the occurrence of preselected nine macrolichen taxa on trees across the UK (Seed et al. 2013; Tregidgo et al. 2013; Welden et al. 2018) or to transplanting oakmoss (*Evernia prunastri*) at private properties in rural and urban areas to survey in- and outdoor air quality in Slovakia (Paoli et al. 2019). Another approach, more targeted to particular stakeholders or environmental activists, has been the use of selected well-recognizable species for detecting potential biodiversity hotspots for conservation (e.g., Nitare 2000; Frati and Brunialti 2023; but see Uliczka et al. 2004 for limitations). Even solely photo-based surveys by trained volunteers can provide valuable biodiversity information, for example in national parks (Casanovas et al. 2014).

The rich lichen biota in forests represents a dilemma for citizen science. On the one hand, lichens remain under-studied (Di Marco et al. 2017) and almost neglected in biodiversity conservation policies (Gonçalves et al. 2021; Oyanedel et al. 2022). Although in the best studied regions, such as boreal Europe and North-America, several quantitative full-assemblage datasets of forest lichens have provided insights into the management impacts at tree (e.g., Lundström et al. 2013, Hämäläinen et al. 2014; Kumar et al. 2017) and stand scales (Lõhmus and Lõhmus 2019), these have seldom contributed to regional Red List assessments (but see, e.g., Lõhmus and Lõhmus 2009). Broad-scale lichen distributions across the changing forest landscapes remain poorly known, while intensive forestry continues to degrade their habitats (e.g., Nascimbene et al. 2013; Lõhmus and Lõhmus 2019; Pykälä 2019) and affects even common species (e.g., Lõhmus et al. 2019; Pykälä et al. 2019; Randlane et al. 2021). On the other hand, complementing these existing datasets through non-expert campaigns runs against the main logic of citizen science: non-professional participants are unlikely to visit remote sites (such as forests), particularly in sparsely populated production areas (such as clear-cut forest landscapes), in search of inconspicuous organisms (cf. Mair and Ruete 2016). The opportunities and limits for that are nevertheless important to understand.

We report on how a citizen-science campaign for untrained participants contributed to knowledge on forest lichen diversity in Estonia, which is a relatively sparsely populated country (on average, 29 people / km^2) that has ca. 50% forest cover in hemiboreal Europe. The campaign was designed to achieve the following aims: (1) to gather nationwide distribution data of epiphytic lichens over forest land, highlighting the ecological contrast between forest trees versus retention trees in cutover sites (previously documented using conventional research: Lõhmus et al. 2006, Lõhmus and Lõhmus 2010), (2) to analyse the potential of the campaign to improve species distribution data, and (3) to explore whether the species data gained with photographic survey are comparable to expert-collected datasets and could complement those for monitoring of common forest lichens.

Materials and methods

The campaign

The campaign "Ready! Set! Lichen!" (in Estonian, "Tähelepanu! Valmis olla! Samblik!") took place from 26 June to 31 October 2021. The aim was to collect observations of epiphytic lichens throughout the territory of Estonia and to engage as many participants as possible. Participants were not expected to be familiar with any lichen species. The field data collection was based solely on digital images (submitted through a special web-based application at www.samblik.ee), which were later ascribed to species by lichenology experts.

In the project period, participants were asked to visit any forest or a cutover site (preferably both) and to spot the largest living tree of any species in each habitat. A geographical positioning device and photo camera were mandatory equipment. Arriving to the tree trunk, the participant was asked: (i) to take the GPS coordinate (automatized on the digital map in the web-based application), and record the tree species and trunk size at breast height; (ii) to locate the most lichen rich place on the tree trunk at eye level, and (iii) to turn smartphone at landscape position and to take sharp images of that trunk area. Up to three photos were possible to upload; these are roughly comparable with conventional 20×20 cm lichen survey plots at breast height. An additional request was (iv) to record, along the whole trunk, the presence of four conspicuous macrolichens of conservation relevance (hereafter: target species): *Lobaria pulmonaria*, *Leptogium saturninum*, *Hypogymnia farinacea* (Nitare 2000; Lõhmus and Lõhmus 2019) and any species from genus *Peltigera* (Liira et al. 2007; Liira and Sepp 2009). These species had to be documented also with a photo upload.

The campaign webpage was available both in Estonian (speaken by 84% of the population; 67% as mother tongue) and in Russian. It included the goals of the campaign, introduction to lichens in general and their importance for forest ecosystems (three video clips), observation sheets and filling guides, photos of each target species as well as video clips about their main morphological characters. The materials were compiled with the help of a professional communication partner to link the request for usable research data with the information needs of untrained participants.

Data extraction, processing and analysis

In total, 1101 tree observations and 1716 photos of their epiphytic cover were uploaded on the campaign web-platform (examples in Online Resource 1). Among 362 participants (327 individuals and 35 'teams' of family, friends or classmates), 49% provided only one observation, while 20 participants made more than six observations and contributed 46% of all observations.

These materials were checked by lichen experts (authors PL and PD) and commented online on a weekly basis (https://samblikud.ee/galerii/#). Altogether 14% of observations were rejected, mostly because of missing or blurred photos (see Online Resource 1) or as duplicate observations. The habitat (forest or cutover site) was confirmed based on the GPS coordinate location using Google Maps satellite view; deviations (e.g., urban or settlement areas) were recorded. Tree species identification was checked based on the photos. Lichen taxa were identified, if possible, from all photos uploaded. The lichens which could not be morphologically identified to the species level were treated as morphogroups or solely at the genus level. For comparative analysis of forest vs. retention trees (*dataset B*, see below), only one photo (preferably the sharpest) per each tree was selected. From that photo, the species list was compiled and total % cover of all lichens (10% step scale; also separately for microlichens, i.e., lichens with a crustose thallus) was assessed relative to the trunk area captured. The assessment was always done by one expert (PL).

For analysis, two datasets were distinguished. *Dataset A* ('distribution dataset') comprised data from all observed trees and photos, including multiple trees sampled from the same forest and cutover sites as well as trees from urban or settlement areas. From this dataset, a test subset of 12 epiphytic species were selected to analyse the contribution of the campaign to records available from 2000 to 2021 in the PlutoF biodiversity data system (https://plutof.ut.ee; Abarenkov et al. 2010). This time period represents the highest activity of full-assemblage research of forest lichens in Estonia accompanied with accurate (GPS based) locality information. Six macrolichens (*Cladonia ochrochlora, Hypocenomyce scalaris*, *Hypogymnia tubulosa*, *Parmelia sulcata*, *Tuckermannopsis chlorophylla*, *Vulpicida pinastri*) and six microlichens (*Acrocordia gemmata*, *Alyxoria varia*, *Bacidia fraxinea*, *Lecanora allophana*, *Lecidea nylanderi*, *Lepra amara*) were chosen post hoc to illustrate this. Selection of the species was based on the rationale to have similar numbers of macro- and microlichens, and species with higher (>30) and lower (<20) observation frequencies in the campaign.

The 2×2 km grid of the European Environment Agency (EEA) for Estonia was used to assign each of the records to a grid cell using QGIS software (Development Team 2021). Thus, a species distribution was described by the number of grid cells with records (area of occupancy). For each species, the contribution of the campaign was calculated as the proportion of new grid cells obtained compared with the PlutoF record cells.

Dataset B ('forest vs retention tree dataset') included only one photo per tree per location (see above). This was used for the comparative analysis of forest vs. retention trees, using two previous Estonian raw datasets as background references: (i) full lichen assemblage surveys in 133 standard forest and cutover study plots of 2 ha size (Lõhmus and Lõhmus 2019) for comparing relative frequencies of species in the campaign dataset; (ii) tree-scale data (two 20×20 cm plots at breast height) on forest and retention trees in four regions in Estonia (Lõhmus et al. 2006) for comparing with lichen cover estimates on the photos taken during the campaign.

To compare lichens on forest trees with those on retention trees (following the design used in Lõhmus et al. 2006), we organized the dataset B as a balanced dataset of spatially close (maximum 10 km) pairs of forest vs. retention trees. Analysis of variance (ANOVA) was used to assess the difference in their mean species number and cover with Statistica® 6.0 software (StatSoft 1984–2001).

Results

Species and distribution data

Out of 947 accepted observations (Online Resource 2), 68% were in forest (two-thirds of these in protected areas), 18% on retention trees, and 14% outside forest land (settlements, parks, farmyards). They included 16 native forest tree species and six introduced tree species (e.g., *Larix sp*. and *Abies sp*.). The most frequently sampled trees were *Pinus sylvestris* (305 observations), *Betula pendula* (178), *Populus tremula* (118), *Quercus robur* (72), and *Picea abies* (71). The observations from forest land (including clear-cuts) were well distributed over the whole mainland of Estonia and in six islands (Fig. 1).

In total 86 lichen-forming species and 33 morphospecies (hereafter as "species") were photo-identified (Online Resources 2 and 3); 55% were microlichens. The proportion of morphospecies was 20% from the total number of observations, but the proportion was 38% for microlichens and only 1% for macrolichens. Most frequent taxa were *Hypogymnia physodes* (on 44% of observed trees), *Phlyctis argena* (43%), *Lepraria spp.* (42%), *Parmelia sulcata* (17%), *Lecidea nylanderi* (15%) and *Ramalina farinacea* (10%). All these species had > 60% frequency also in the expert-based reference study of forest and cutover sites (Online Resource 3). There were 53 observations of species of conservation concern, including nationally protected (e.g., *Carbonicola anthracophila*, *Parmeliella triptophylla*), threatened (e.g., *Chrysothrix flavovirens*) and/or indicator species of woodland key habitats (e.g., *Alyxoria varia*, *Arthonia leucopellaea*, *Bacidia rubella*) (Online Resource 3). The four target macrolichens were infrequently and often erroneously reported (27% of 144 observations could be confirmed; including *Leptogium saturninum* and *Hypogymnia farinacea* only

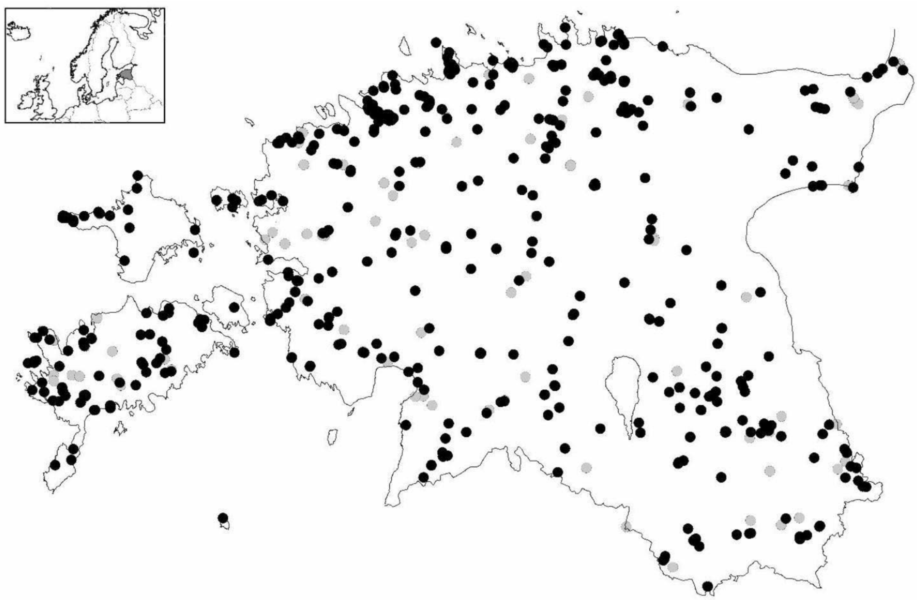

Fig. 1 Locations of forest trees (black dots) and retention trees (grey dots) surveyed in the citizen-science campaign "Ready! Set! Lichen!" in Estonia in 2021

observed once). Among the target species, the campaign improved known distribution only for *Lobaria pulmonaria* (four new 2×2 km grid cells).

The data on test-subset of 12 epiphytic species comprised 5214 national records (3593 unique 2×2 km grid-cells occurrences), with 10.4% contributed by the campaign. The average contribution of the campaign per species was 13.4% ± 8.2% (SD) cells, with almost three times larger relative increases in more abundant than less abundant species (Online Resource 4). Thus, the most abundant microlichen considered, *Lecidea nylanderi*, had the largest increase (31%) (Online Resource 5), followed by the most abundant macrolichen *Parmelia sulcata* (22%). On average, microlichen areas of occupancy expanded even more than in the macrolichens (15.2% vs. 11.5%).

Lichens on forest trees versus retention trees

The total number of lichen-forming species observed on the photos was 106 on forest trees (n=475) and 68 on retention trees (n=132). The mean species number per photo did not differ significantly between forest and retention trees (on average, 3.4 and 3.3 species, respectively), also for macro- and microlichen species considered separately (Fig. 2A). Mean lichen cover per photo was 65% on forest and 54% on retention trees; the difference was significant overall (ANOVA: $F_1=26.6$, $p<0.01$) and for macrolichens ($F_1=12.8$, $p<0.01$), but not for microlichens (Fig. 2B). Comparing the campaign and the reference datasets

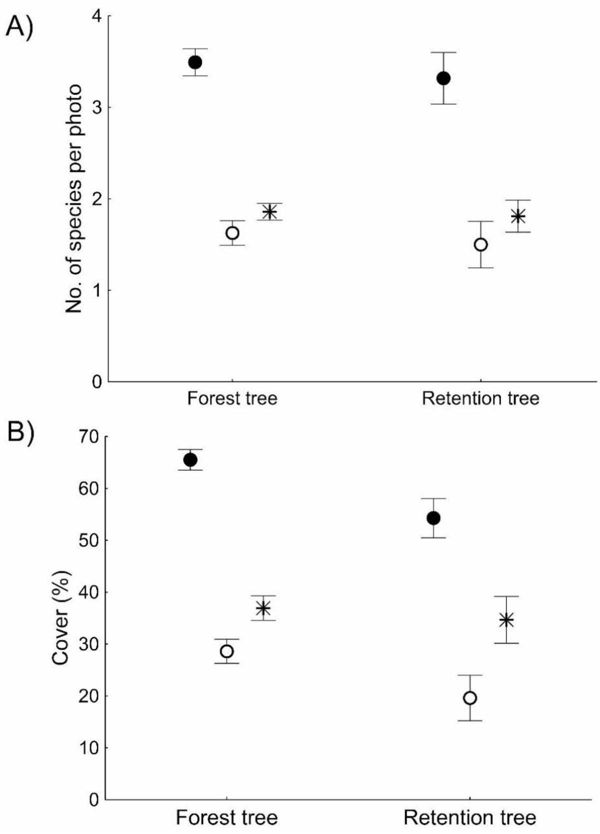

Fig. 2 Mean number of lichen species **(A)** and total lichen cover **(B)** per photo on forest (n=475) and retention trees (n=132) (filled circles). Values of the same variables are presented separately also for macrolichens (empty circle) and microlichens (asterisk). Whiskers are ±95% confidence intervals

revealed generally higher lichen cover values in the former ($F_1 = 8.5$, $p < 0.01$; significant contrasts between forest and retained trees in birches and pines: Tukey HSD test, $p < 0.01$). In relative terms, the campaign confirmed tree species differences that were showed also in the expert-based study, except in the case of aspens (Fig. 3).

Discussion

The Estonian citizen science campaign for forest lichens revealed several opportunities and limitations worth consideration in monitoring and conservation of inconspicuous organisms. We have synthesized these lessons into a tentative list of major contributions that such campaigns could make to biodiversity and conservation research (Table 1). Below, we focus on the main methodological findings of our case study.

First, the sampling was attended by hundreds of participants, but <5% of these provided most of the material. This pattern may have emerged due to, for example: (i) short-term curiosity for enigmatic organisms – lichens are little recognised outside a small group of specialists, but easily seen once noticed; (ii) beginners were not stressed with identification tasks; (iii) the enthusiastic fraction of participants may have been motivated by a communicated awareness that the data will have instant value for researchers (see also Day et al. 2022). What we do not know for our project is how many people went out but did not send their photos, and whether this could further bias the sample received (Johnston et al. 2023).

Second, more than a half of the observations were made in state forests in nature reserves, and clearly more often in forest trees than in retention trees on clear-cuts. Thus, despite a recommended paired sampling, the dataset became biased toward recreational forest areas attractive for urban citizens instead of typical managed forest landscapes (particularly private forest). In Estonia, this resembles not only the behaviour of human berry-pickers (Remm et al. 2018), but also of historical (haphazard) lichenological sampling by professionals (Lõhmus and Lõhmus 2009). It is unlikely that such preferences can be overcome by general campaigns. Rather, the poorly represented ecosystems should be purposefully addressed by expert programs, while private lands could be addressed by targeted requests to land-owners.

Third, the "blind photographic" campaign revealed many lichen species for a rather restricted microhabitat (relatively small tree-trunk area at the breast height), without including other species rich microhabitats, like tree base or branches (Holien 1997; Boch et al. 2013; Marmor et al. 2013). It partly results from the diversity of tree species sampled and the recommended focus on the largest living tree around (cf. Ellis 2012). The fact that half of the species and total observations were of microlichens can be considered an advantage of a "blind photographic" campaign when the species sampling does not depend on what species the participant is able to detect on the tree trunk (cf. Johnston et al. 2023). Participants may have preferred to photograph the place with more macrolichens, but still both macro- and microlichens were captured on the photos, with microlichens having even slightly higher cover. In addition, most of the observed 86 species are common in Estonian forest land and well documented in expert surveys (Lõhmus and Lõhmus 2019). However, lichen identification often requires more information than a photograph can provide (notably micro-morphology and thallus chemistry). Machine learning for species recognition will not solve these limitations either (McMullin and Allen 2022) and hence many observa-

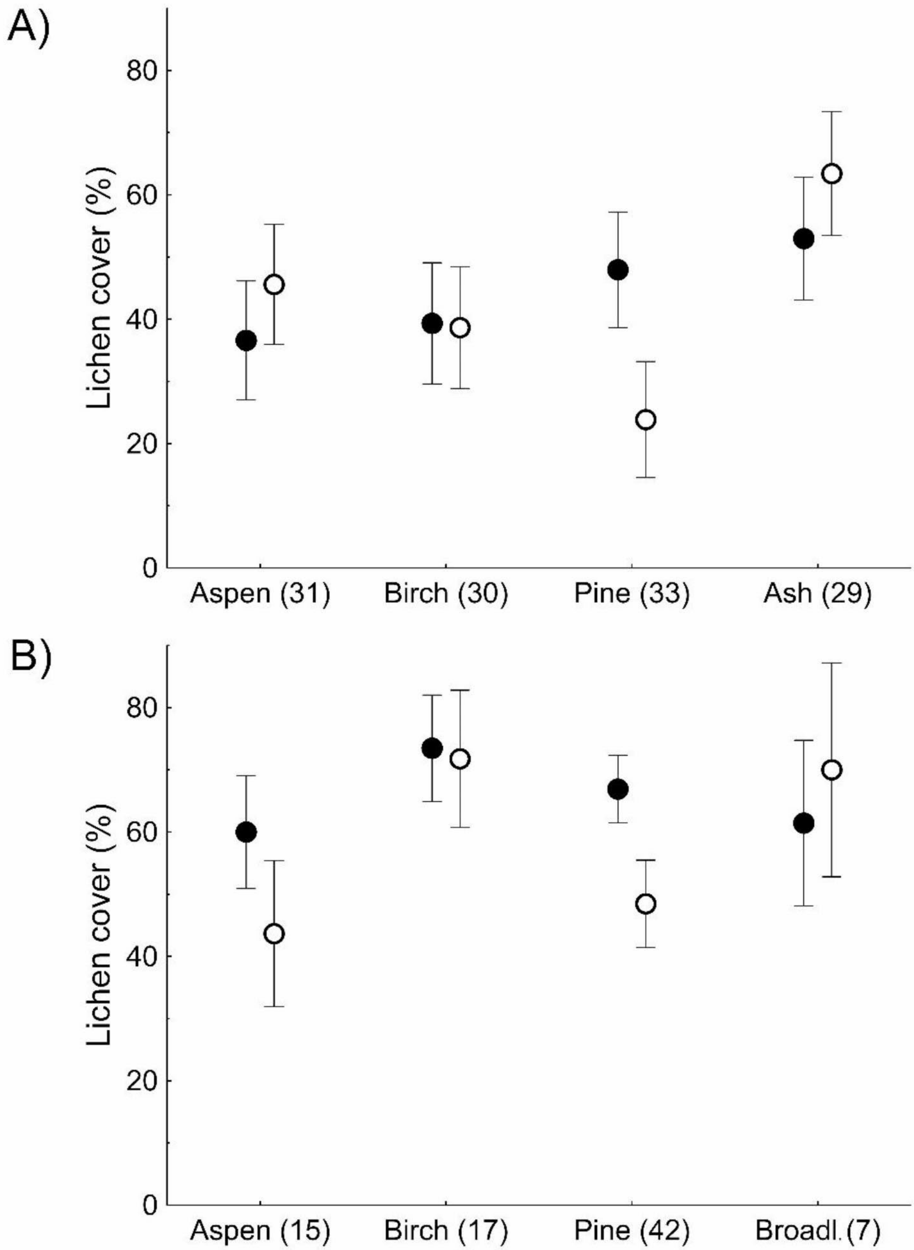

Fig. 3 Comparative mean (±95%CI) lichen cover on forest (filled circles) and retention trees (empty circle) by tree species. **(A)** The reference dataset using expert assessment (raw data of Lõhmus et al. 2006). **(B)** The photo-based citizen-campaign. The number in the brackets indicate sample sizes of paired trees; 'Broadl.' – nemoral broad-leaved trees

Table 1 Conservation research topics to which citizen science (CS) approach with lichens could contribute, their likely limitations, and quality improvement activities

Research topic	CS contribution	Main limitations	Quality improvement
1. Identifying biodiversity hotspots	Recording conspicuous indicator species [1,2] across landscapes	Sampling bias for better known (less remote) areas; Missing valuable hotspots	Motivate sampling in less accessible areas; Follow-up expert surveys in and around locations found
2. Broad-scale distributions and frequencies of lichens	Presence-only records of all species; Frequencies of common species based on 'blind photographic' approach	Sampling within camera reach; Identification limitations, incl. morphospecies bias in microlichens [3]	Advanced digital technologies, e.g. UV-photography and image processing [4]
3. Species distribution models for quantitative conservation assessment	Providing training and ground-check data [5]	Insufficient representation of modelled range; Identification limitations	Parallel use and combining with expert datasets
4. Management impact assessments	Photo-recording of management contrasts or gradients across landscapes	Rigorous sampling rules not followed [3]; Limitations of photo-sampling (see above)	Use simple (e.g., paired) designs and easily recognizable conditions
5. Remote environmental impacts (e.g., air pollution; climate change)	Survey of preselected taxa or morpho-functional groups; Experiments with transplants [6]	Single model species and limited substrates may be insufficient [7]; Misinterpretation of thallus condition	Photodocumenting; Simple reliable methods for condition and abundance estimation
6. Population viability over time in permanent plots	Recording trends and fluctuations in colonies and assemblages	Substrate-level succession as confounding factor; Plot abandonment	Easily accessible plots; Quality of photo and location archives

References: [1] Lõhmus and Lõhmus 2019; [2] Nitare 2000; [3] current study, [4] Guedes et al. 2022; [5] Casanovas et al. 2015; [6] Paoli et al. 2019; [7] Frati and Brunialti 2023 tions cannot be identified accurately. Morphospecies or parataxonomical units can be still used as species surrogates to analyse lichen diversity (Casanovas et al. 2014), but attention should be paid on possible systematic skewness (toward morphospecies of microlichens in the current study).

Fourth, the threatened target species used in the current study (*Lobaria pulmonaria*, *Leptogium saturninum*, *Hypogymnia farinacea*) were all macrolichens that can be easily noticed in the field and accurately identified on the photo. A low number of records of these species was partly expected due to their scarcity and aggregation to unmanaged forests (Lõhmus and Lõhmus 2019). In fact, a lack of their observations on retention-trees is still informative for understanding landscape-scale continuity of the populations. Nevertheless, the overall record scarcity suggests that a mass participation approach to citizen science may not pay off in case of some rare or sparsely distributed habitat specialists.

Finally, we measured the contribution of citizen-science biodiversity data as the amount of additional distribution data. We found that these contributions were larger for common lichens, including the inconspicuous microlichens. This indicates that the distributions of common species are relatively more underestimated by expert data. Risk of unnoticed decline of common species is relatively high, because only one-third of forest lichens appear to tolerate intensive even-aged forest management (Lõhmus and Lõhmus 2019) that is practiced widely in North-European countries (Gustafsson et al. 2020). At the same time, population size reduction (criterion A) is the only out of four criteria that applies to the red-listing of widespread species by the IUCN system (IUCN 2022), but documenting declines of common forest species is challenging. It requires representative monitoring systems or observations collected across broad spatial and temporal scales (e.g., Nellis and Volke 2019), that have not been elaborated for forest lichens so far (but see Asta et al. 2002).

Citizen science protocols need to adhere to scientific methods in order to contribute directly to ecological monitoring and local decision-making (e.g., Gouraguine et al. 2019; Aavik et al. 2020). Our comparisons with the conventional research designs supported previous studies showing that lichens can be life-boated on retention trees in a short term (Lõhmus and Lõhmus 2010; Lundström et al. 2013, Hämäläinen et al. 2014). Some smaller deviations of the citizen data (e.g., lichen cover on forest and retention trees within tree species) could be related to low and unbalanced sample sizes of tree species and tree pairs. However, for long-term monitoring of life-boating effect of retention trees the repeatability of campaign data becomes critical. Citizen science campaigns are not always cost-effective in terms of human resources and money for spreading the information and attracting participants compared to expert costs (Alfonso et al. 2022), especially if large samples and reliable results are needed for sparsely populated regions.

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Author contributions All authors contributed to the study conception and design. Data analysis was performed by Piret Lõhmus and Ovidiu Copoț. The first draft of the manuscript was written by Piret Lõhmus and Polina Degtjarenko; the other authors revised the draft. All authors read and approved the final draft of manuscript.

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Data Availability Raw data are available as electronical supplementary.

Declarations

Competing interests The authors declare no competing interests.

References

Aavik T, Carmona CP, Träger S, Kaldra M, Reinula I, Conti E, Keller B, Helm A, Hiiesalu I, Hool K, Kaisel M, Oja T, Lotman S, Pärtel M (2020) Landscape context and plant population size affect morph frequencies in heterostylous *Primula veris* — results of a nationwide citizen-science campaign. J Ecol 108:2169–2183. https://doi.org/10.1111/1365-2745.13488

Abarenkov K, Tedersoo L, Nilsson R, Vellak K, Saar I, Veldre V, Parmasto E, Prous M, Aan A, Ots M, Kurina O, Ostonen I, Jõgeva J, Halapuu S, Põldmaa K, Toots M, Truu J, Larsson K-H, Kõljalg U (2010) PlutoF - a web based Workbench for Ecological and Taxonomic Research, with an online implementation for fungal ITS sequences. Evolutionary Bioinf 6:189–196. https://doi.org/10.4137/EBO.S6271

Alfonso L, Gharesifard M, When U (2022) Analysing the value of environmental citizen-generated data: complementarity and cost per observation. J Environ Manage 303:114157. https://doi.org/10.1016/j.jenvman.2021.114157

Asta J, Erhardt W, Ferretti M, Fornasier F, Kirschbaum U, Nimis PL, Purvis OW, Pirintsos S, Scheidegger C, Van Haluwyn C, Wirth V (2002) European guideline for mapping lichen diversity as an indicator of environmental stress. British Lichen Society, London

Boch S, Müller J, Prati D, Blaser S, Fischer M (2013) Up in the tree – the overlooked richness of Bryophytes and Lichens in Tree crowns. PLoS ONE 8(12):e84913. https://doi.org/10.1371/journal.pone.0084913

Bonney R, Cooper CB, Dickinson J, Kelling S, Phillips T, Rosenberg KV, Shirk J (2009) Citizen Science: a developing Tool for Expanding Science Knowledge and scientific literacy. BioScience 59:977–984. https://doi.org/10.1525/bio.2009.59.11.9

Casanovas P, Lynch HJ, Fagan WF (2014) Using citizen science to estimate lichen diversity. Biol Conserv 171:1–8. https://doi.org/10.1016/j.biocon.2013.12.020

Casanovas P, Black M, Fretwell P, Convey P (2015) Mapping lichen distribution on the Antarctic Peninsula using remote sensing, lichen spectra and photographic documentation by citizen scientists. Polar Res 34:25633. https://doi.org/10.3402/polar.v34.25633

Day G, Fuller RA, Nichols C, Dean AJ (2022) Characteristics of immersive citizen science experiences that drive conservation engagement. People and Nature 4:983–995. https://doi.org/10.1002/pan3.10332

Development Team QGIS (2021) QGIS Geographic Information System. Open Source Geospatial Foundation. http://qgis.org. Accessed by 26 April 2022

Di Marco M, Chapman S, Althor G, Kearney S, Besancon C, Butt N, Maina JM, Possingham HP, von Bieberstein KR, Venter O, Watson JE (2017) Changing trends and persisting biases in three decades of conservation science. Glob Ecol Conserv 10:32–42. https://doi.org/10.1016/j.gecco.2017.01.008

Dickinson JL, Shirk J, Bonter D, Bonney R, Crain RL, Martin J, Phillips T, Purcell K (2012) The current state of citizen science as a tool for ecological research and public engagement. Front Ecol Environ 10:291–297. https://doi.org/10.1890/110236

Ellis CJ (2012) Lichen epiphyte diversity: a species, community and trait-based review. Perspect Plant Ecol Evol Syst 14:131–152. https://doi.org/10.1016/j.ppees.2011.10.001

Frati L, Brunialti G (2023) Recent trends and future challenges for lichen biomonitoring in forests. Forests 14:647. https://doi.org/10.3390/f14030647

Gonçalves SC, Haelewaters D, Furci G, Mueller GM (2021) Include all fungi in biodiversity goals. Science 373:403–403. https://doi.org/10.1126/science.abk1312

Gouraguine A, Moranta J, Ruiz-Frau A, Hinz H, Reñones O, Ferse SC, Jompa J, Smith DJ (2019) Citizen science in data and resource-limited areas: a tool to detect long-term ecosystem changes. PLoS ONE 14:e0210007. https://doi.org/10.1371/journal.pone.0210007

Guedes P, Oliveira MA, Branquinho C, Silva JN (2022) Image analysis for automatic measurement of crustose lichens. https://doi.org/10.48550/arXiv.2203.00787. arXiv:2203.00787 [cs.CV]

Gustafsson L, Hannerz M, Koivula M, Shorohova E, Vanha-Majamaa I, Weslien J (2020) Research on retention forestry in Northern Europe. Ecol Process 9:1–13. https://doi.org/10.1186/s13717-019-0208-2

Hämäläinen A, Kouki J, Lõhmus P (2014) The value of retained Scots pines and their dead wood legacies for lichen diversity in clear-cut forests: the effects of retention level and prescribed burning. For Ecol Manag 324:89–100. https://doi.org/10.1016/j.foreco.2014.04.016

Holien H (1997) The lichen flora on *Picea abies* in a suboceanic spruce forest area in Central Norway with emphasis on the relationship to site and stand parameters. Nord J Bot 17:55–76. https://doi.org/10.1111/j.1756-1051.1997.tb00290.x

IUCN (2022) IUCN Standards and Petitions Committee. Guidelines for Using the IUCN Red List Categories and Criteria. Version 15.1. Prepared by the Standards and Petitions Committee. https://www.iucnredlist.org/documents/RedListGuidelines.pdf. Accessed by 27 April 2023

Johnston A, Matechou E, Dennis EB (2023) Outstanding challenges and future directions for biodiversity monitoring using citizen science data. Methods Ecol Evol 14:103–116. https://doi.org/10.1111/2041-210X.13834

Kullenberg C, Kasperowski D (2016) What is Citizen Science? – A scientometric Meta-analysis. PLoS ONE 11:e0147152. https://doi.org/10.1371/journal.pone.0147152

Kumar P, Chen HY, Thomas SC, Shahi C (2017) Effects of coarse woody debris on plant and lichen species composition in boreal forests. J Veg Sci 28:389–400. https://doi.org/10.1111/jvs.12485

Liira J, Sepp T (2009) Indicators of structural and habitat natural quality in boreo-nemoral forests along the management gradient. Ann Bot Fenn 46:308–325. https://doi.org/10.5735/085.046.0407

Liira J, Sepp T, Parrest O (2007) The forest structure and ecosystem quality in conditions of anthropogenic disturbance along productivity gradient. For Ecol Manage 250:34–46. https://doi.org/10.1016/j.foreco.2007.03.007

Lõhmus P, Lõhmus A (2009) The importance of representative inventories for lichen conservation assessments: the case of *Cladonia norvegica* and *C. parasitica*. Lichenologist 41:61–67. https://doi.org/10.1017/S002428290900807X

Lõhmus A, Lõhmus P (2010) Epiphyte communities on the trunks of retention trees stabilise in 5 years after timber harvesting, but remain threatened due to tree loss. Biol Conserv 143:891–898. https://doi.org/10.1016/j.biocon.2009.12.036

Lõhmus P, Lõhmus A (2019) The potential of production forests for sustaining lichen diversity: a perspective on sustainable forest management. Forests 10:1063. https://doi.org/10.3390/f10121063

Lõhmus P, Rosenvald R, Lõhmus A (2006) Effectiveness of solitary retention trees for conserving epiphytes: differential short-term responses of bryophytes and lichens. Can J for Res 36:1319–1330. https://doi.org/10.1139/x06-032

Lõhmus P, Marmor L, Jüriado I, Suija A, Oja E, Degtjarenko P, Randlane T (2019) Red list of Estonian lichens: revision in 2019. Folia Cryptogamica Estonica 56:63–76. https://doi.org/10.12697/fce.2019.56.07

Lundström J, Jonsson F, Perhans K, Gustafsson L (2013) Lichen species richness on retained aspens increases with time since clear-cutting. For Ecol Manage 293:49–56. https://doi.org/10.1016/j.foreco.2012.12.027

Mair L, Ruete A (2016) Explaining spatial variation in the recording effort of citizen science data across multiple taxa. PLoS ONE 11:e0147796. https://doi.org/10.1371/journal.pone.0147796

Marmor L, Tõrra T, Saag L, Leppik E, Randlane T (2013) Lichens on *Picea abies* and *Pinus sylvestris* – from tree bottom to the top. Lichenologist 45:51–63. https://doi.org/10.1017/S0024282912000564

McMullin RT, Allen JL (2022) An assessment of data accuracy and best practice recommendations for observations of lichens and other taxonomically difficult taxa on iNaturalist. Botany 100:491–497. https://doi.org/10.1139/cjb-2021-0160

Meschini M, Prati F, Simoncini GA, Airi V, Caroselli E, Prada F, Marchini C, Toffolo MM, Branchini S, Brambilla V, Covi C, Goffredo S (2021) Environmental awareness gained during a Citizen Science Project in Touristic Resorts is maintained after 3 years since participation. Front Mar Sci 8:584644. https://doi.org/10.3389/fmars.2021.584644

Nascimbene J, Thor G, Nimis PL (2013) Effects of forest management on epiphytic lichens in temperate deciduous forests of Europe–A review. For Ecol Manag 298:27–38. https://doi.org/10.1016/j.foreco.2013.03.008

Nellis R, Volke V (2019) Metsalindude arvukuse muutused perioodil 1983–2018. Hirundo 32:63–80

Nitare J (ed) (2000) Signalarter—indikatorer på skyddsvärd skog: flora över kryptogamer. Skogsstyrelsens Förlag, Jönköping

Oyanedel R, Hinsley A, Dentinger BTM, Milner-Gulland EJ, Furci G (2022) A way forward for wild fungi in international sustainability policy. Conserv Lett 15:e12882. https://doi.org/10.1111/conl.12882

Paoli L, Fačkovcová Z, Guttová A, Maccelli C, Kresáňová K, Loppi S (2019) *Evernia* goes to school: Bioaccumulation of heavy metals and photosynthetic performance in lichen transplants exposed indoors and outdoors in public and private environments. Plants 8:125. https://doi.org/10.3390/plants8050125

Pocock MJ, Tweddle JC, Savage J, Robinson LD, Roy HE (2017) The diversity and evolution of ecological and environmental citizen science. PLoS ONE 12(4):e0172579. https://doi.org/10.1371/journal.pone.0172579

Pykälä J (2019) Habitat loss and deterioration explain the disappearance of populations of threatened vascular plants, bryophytes and lichens in a hemiboreal landscape. Glob Ecol Conserv 18:e00610. https://doi.org/10.1016/j.gecco.2019.e00610

Pykälä J, Jääskeläinen K, Rämä H, Launis A, Vitikainen O, Puolasmaa A (2019) Lichens. In: Hyvärinen E, Juslén A, Kemppainen E, Uddström A, Liukko U-M (eds) The 2019 Red list of finnish species. Ministry of the Environment & Finnish Environment Institute, Helsinki, pp 263–312

Randlane T, Jüriado I, Degtjarenko P, Saag A (2021) New assessment of Least Concern lichens in the Red List of Estonia: are common species still common? Folia Cryptogamica Estonica 58:199–212. https://doi.org/10.12697/fce.2021.58.20

Remm L, Rünkla M, Lõhmus A (2018) How bilberry pickers use Estonian forests: implications for sustaining a non-timber value. Balt For 24:287–295

Seed L, Wolseley P, Gosling L, Davies L, Power SA (2013) Modelling relationships between lichen bioindicators, air quality and climate on a national scale: results from the UK OPAL air survey. Environ Pollut 182:437–447. https://doi.org/10.1016/j.envpol.2013.07.045

SEP (2013) Science Communication Unit, University of the West of England, Bristol. Science for Environment Policy Indepth Report: Environmental Citizen Science. Report produced for the European Commission DG Environment, December 2013. http://ec.europa.eu/science-environment-policy. Accessed by 26 April 2022

Tregidgo DJ, West SE, Ashmore MR (2013) Can citizen science produce good science? Testing the OPAL Air Survey methodology, using lichens as indicators of nitrogenous pollution. Environ Pollut 182:448–451. https://doi.org/10.1016/j.envpol.2013.03.034

Uliczka H, Angelstam P, Roberge JM (2004) Indicator species and biodiversity monitoring systems for non-industrial private forest owners: is there a communication problem? Ecol Bull 51:379–384

Underwood E, Taylor K, Tucker G (2018) The use of biodiversity data in spatial planning and impact assessment in Europe. Res Ideas Outcomes 4:e28045. https://doi.org/10.3897/rio.4.e28045

Welden NA, Wolseley PA, Ashmore MR (2018) Citizen science identifies the effects of nitrogen deposition, climate and tree species on epiphytic lichens across the UK. Environ Pollut 232:80–89. https://doi.org/10.1016/j.envpol.2017.09.020

Will-Wolf S (2002) Monitoring regional status and trends in forest health with lichen communities: the United States Forest Service approach. In: Nimis PL, Scheidegger C, Wolseley PA (eds) Monitoring with lichens — monitoring lichens. NATO Science Series, vol 7. Springer, Dordrecht, pp 353–357