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ARTICLE

An assessment of data accuracy and best practice recommendations for observations of lichens and other taxonomically difficult taxa on iNaturalist

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Abstract: We assess the identification accuracy of 'research grade' observations of lichens posted on the online platform iNaturalist. Our results show that these observations are frequently misidentified or lack the necessary chemical and (or) microscopic information for accurate identification. Lichens are a taxonomically difficult group, but they are ubiquitous and eye-catching and are regularly the subject of observations posted on iNaturalist. Therefore, we provide best practice recommendations for posting lichen observations and commenting on observations. Data from iNaturalist are a valuable tool for understanding and managing biodiversity, particularly at this crucial time when large scale biodiversity decline is occurring globally. However, the data must be accurate for them to effectively support biodiversity conservation efforts. Our recommendations are also applicable to other taxonomically difficult taxa.

Key words: biodiversity, conservation, citizen science, species at risk, data accuracy.

Résumé : Les auteurs évaluent l'exactitude d'identification des observations de lichens de qualité recherche affichées sur la plateforme en ligne iNaturalist. Leurs résultats révèlent que ces observations sont souvent mal identifiées ou ne comportent pas les informations chimiques ou microscopiques nécessaires à une identification exacte. Les lichens constituent un groupe taxonomiquement difficile, mais ils sont omniprésents et ne passent pas inaperçus, et ils font régulièrement l'objet d'observations affichées sur iNaturalist. Par conséquent, les auteurs formulent des recommandations en matière de bonnes pratiques pour afficher des observations de lichens et commenter les observations. Les données de iNaturalist sont un outil précieux pour la compréhension et la gestion de la biodiversité, en particulier en cette période cruciale où le déclin de la biodiversité à grande échelle se produit à l'échelle mondiale. Cependant, les données doivent être exactes pour qu'elles puissent soutenir efficacement les efforts de conservation de la biodiversité. Leurs recommandations sont également applicables à d'autres taxons taxonomiquement difficiles. [Traduit par la Rédaction]

Mots-clés : biodiversité, conservation, science citoyenne, espèces en péril, exactitude des données.

Introduction

iNaturalist is an online platform where species observations worldwide can be shared and mapped by citizen scientists and professionals. The site was created in 2008 by students at the University of California, Berkeley, and it is now run by the California Academy of Sciences and the National Geographic Society (iNaturalist 2020). Educators often use iNaturalist to help students foster direct engagement with biodiversity and to build awareness of a wide range of species, which contributes to reducing biodiversity naivety and building a foundation for successful conservation efforts (Niemiller et al. 2021). As of 17 March 2020, there were 2 201 161 registered users who had made 37 946 347 observations (iNaturalist 2020).

Observations on iNaturalist record species in space and time. To help confirm the identity of the species posted, images or sound files are uploaded, and species recognition software provides identification suggestions. However, whether a name is provided by the observer or not, a verification process is in place that crowdsources identifications from other iNaturalist users. Observations become 'research grade' when they are at the genus level or finer, are confirmed by two or more users (which includes an initial identification suggested by the observer), two thirds or more of the identifiers are in

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agreement, there are no active flags, and no contradicting data quality assessments. As of 17 March 2020, there were 20 273 874 research grade observations (iNaturalist 2020). Research grade observations are then aggregated on other databases such as the Global Biodiversity Information Facility (GBIF) (iNaturalist 2020).

As of 8 April 2020, the GBIF database contained 1 404 554 788 occurrence records (GBIF 2021). These records are mostly linked to physical specimens, but observations are also included such as those generated by the iNaturalist platform. Both GBIF and iNaturalist databases are important tools for conservationists, ecologists, naturalists, and taxonomists, but they rely on accurate identifications. Records from iNaturalist can be excluded when searching GBIF by omitting all observations with no vouchers. However, this extensive dataset provides valuable information and warrants inclusion in the development of conservation strategies, ecological modelling, and taxonomic revisions. Therefore, generating high-quality data are critical for users to confidently include observations.

To measure data quality on iNaturalist, Wittmann et al. (2019) trained 10 volunteers how to record and upload observations. They focused on reptiles and amphibians in California and generated 1169 new observations. Due to fast moving specimens resulting in blurry images, the authors determined that 18% of the images could not be verified to species level. Research grade designation was given to 45% of the observations through crowdsourcing, all of which were accurately identified. It is not surprising that larger organisms with relatively distinctive morphological characters are reliably identified on iNaturalist (Wittmann et al. 2019; Unger et al. 2021). However, smaller, more taxonomically difficult species such as lichens, often require more information for identification than a photograph can provide.

Lichens are composite organisms comprised primarily of a mycobiont (fungus) and a photobiont (algae or cyanobacteria, or occasionally both) (Brodo et al. 2001). This diverse group includes a wide variety of colors, shapes, and sizes, and species occur in most terrestrial environments globally (Smith et al. 2009; Allen and Lendemer 2021; Brodo et al. 2001). Therefore, because lichens are photogenic and ubiquitous, and they are present throughout the year (i.e., they do not change with the seasons), they are frequently observed by iNaturalist users. However, lichens cannot always be identified by external macromorphology alone. There are hundreds of chemicals produced by lichens, which give them their wide range of colors, and these chemicals are important for the identification of many species (Orange et al. 2010). The chemistry in some species can only be detected by ultraviolet light, spot tests using reagents, or by thin layer chromatography (Orange et al. 2010). As a result, photographs alone are not sufficient to identify many species. Microscopy is also required to identify numerous lichens. There are 19 387 described lichen species globally (Lücking et al. 2017), and the differences between many of them can be subtle and often internal, requiring dissection and microscopy for identification. Consequently, information about the chemicals produced and internal morphology is required for the accurate identification of many lichen species.

Herein, we provide an assessment of the identification accuracy of research grade observations of lichens posted on iNaturalist. We also provide a list of best practices for posting lichens on the platform. These recommendations are applicable to other taxonomically difficult taxa as well. The data generated by iNaturalist are used widely to understand species' distributions and frequencies, so accurate identification is essential.

Methods

To evaluate the identification accuracy of research grade observations of lichens on iNaturalist, we selected five species in three categories: (*i*) species that can be identified confidently and easily by morphology alone, (*ii*) species that require dissection and microscopy to confidently identify, and (*iii*) species that require chemical analyses to identify. To better understand the identification accuracy of rare species, we also evaluated all lichens listed and protected by the Canadian Species at Risk Act (15 species) and the United States Endangered Species Act (two species) (USFWS 2007, 2013; SARA 2020). For each species in each category, we evaluated 50 random research grade observations on iNaturalist while ensuring they were made by a wide variety of users. We recorded the number of observations correctly identified, those that could not be identified with the data provided (e.g., photograph was too blurry, taken from too far away, or diagnostic features were not included), and those that were clear misidentifications. Based on our experience evaluating these observations, and as regular users of iNaturalist, we developed a list of best practices for posting observations and for commenting on observations to help to improve the accuracy of lichen identifications on the platform.

Results

In each of the four categories we assessed, there were a considerable number of misidentifications and identifications lacking the necessary diagnostic information for confirmation (Fig. 1). For species that required only macromorphology for accurate identification, 148 (59%) of the observations were correct (Table 1). For observations that required microscopy, only 11 (7%) included images or notes about the internal morphology necessary for accurate identification (Table 2). For observations that required chemical analyses, only nine (5%) noted the results of chemical tests required for accurate identification (Table 3). Of the rare lichen observations examined, one species (*Collema coniophilum* Goward) had no observations, but of the remaining species, 288 (73%) were accurately identified and included chemical or

Fig. 1. iNaturalist research grade lichen observations. Results from the four categories assessed in our study, which are as follows: morphology, species that can be identified confidently and easily by macromorphology alone; microscopy, species that require dissection and microscopy to confidently identify; chemistry, species that require chemical analyses to confidently identify; rare species, all lichens listed and protected by the Canadian Species at Risk Act (15 species) and the United States Endangered Species Act (two species) (USFWS 2007, 2013; SARA 2020). [Color online.]

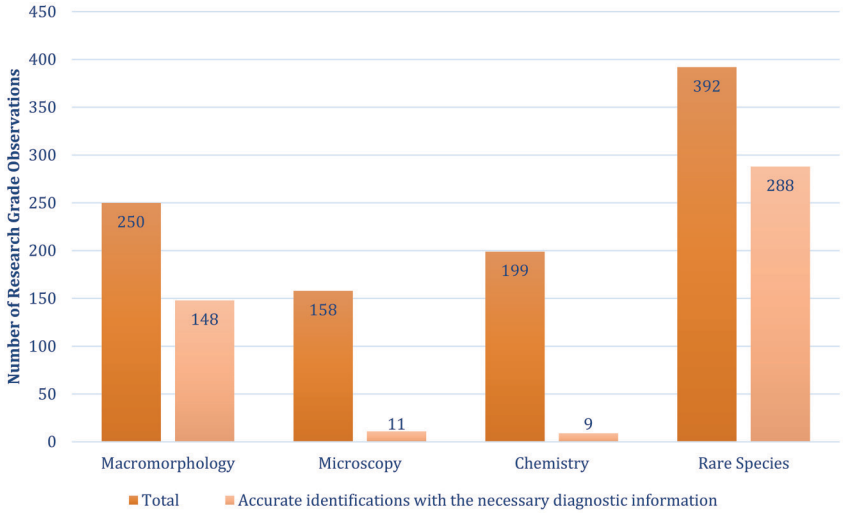

Table 1. Examples of research grade observations on iNaturalist of common lichens that can be identified morphologically.

Species	No. of research grade observations	No. of research grade observations examined	No. and % of research grade observations identified correctly	No. and % of research grade observations that cannot be confirmed with the data available	No and % of research grade observations identified incorrectly
Flavoparmelia caperata	6079	50	35 (70%)	8 (16%)	7 (14%)
Hypogymnia tubulosa	784	50	42 (84%)	4 (8%)	4 (8%)
Parmelia squarrosa	277	50	10 (20%)	39 (78%)	1 (2%)
Parmeliopsis ambigua	168	50	41 (82%)	8 (16%)	1 (2%)
Usnea longissima	737	50	43 (86%)	2 (4%)	5 (10%)

microscopy notes when required (Table 4). The complete results are provided in Supplementary Material 1[1].

Discussion

Our assessment shows that a high number of lichen observations on iNaturalist are misidentified or lack the necessary microscopic and (or) chemical information required for accurate identification. As a result, we provide recommendations for posting observations of lichens and other taxonomically difficult taxa, and for commenting on observations.

Posting observations

To ensure lichen observations on iNaturalist are confidently identifiable, multiple steps must be taken. Some steps are applicable to all observations (e.g., taking a clear photograph), whereas others are specific to taxa that cannot be readily field identified (e.g., notes on chemical tests). Here we provide recommendations for generating lichen observations that are confidently identifiable.

(i) **Become familiar with the iNaturalist platform.** There are helpful introductory videos and text provided by iNaturalist. Spending a small amount of time reviewing this information will help to improve the quality of observations.

(ii) **Take clear, well-lit pictures.** The quality of the photographs is essential. Photographs must be in focus, which can be difficult to achieve for small taxa. Light balance and color should also be as close to reality as possible. Take many pictures to ensure at least one will be high enough quality, and consider post-processing of photographs before posting to fix any lighting or color issues.

[1]Supplementary data are available with the article at https://doi.org/10.1139/cjb-2021-0160.

Table 2. Example of lichens requiring microscopy for species level identification.

Species	No. of research grade observations	No. of research grade observations examined	No. and % of research grade observations identified correctly	No. and % of research grade observations that cannot be confirmed with the available data	No. and % of research grade observations identified incorrectly
Lecanora hybocarpa	131	50	1 (2%)	49 (98%)	0 (0%)
Amandinea punctata	45	45	10 (22%)	35 (78%)	0 (0%)
Rhizocarpon geographicum	879	50	0 (0%)	50 (100%)	0 (0%)
Melanohalea subolivacea	6	6	0 (0%)	6 (100%)	0 (0%)
Calicium parvum	7	7	0 (0%)	7 (100%)	0 (0%)

Table 3. Example of lichens species requiring chemical analysis for accurate identification.

Species	No. of research grade observations	No. of research grade observations examined	No. of research grade observations with the necessary chemical tests	No. and % of research grade potentially misidentified due to lack of chemical tests	No. and % of research grade misidentified
Cetrelia olivetorum	73	50	7 (14%)	43 (86%)	0 (0%)
Alectoria sarmentosa	167	50	1 (2%)	46 (92%)	3 (6%)
Cladonia chlorophaea	360	50	0 (0%)	43 (86%)	7 (14%)
Ropalospora viridis	34	34	1 (3%)	33 (97%)	0 (0%)
Lepraria membranacea	15	15	0 (0%)	15 (100%)	0 (0%)

(iii) **Consider your photography equipment.** Most iNaturalist users take photographs with cellular phones. Phone cameras can be augmented with hand lenses to take magnified photographs. There are also tripods and other stabilizing devices available as phone attachments that will considerably improve the quality of the images. When using a camera, whether it is a point-and-shoot or DSLR, use a tripod and a timed delay setting so photographs are in focus. These cameras typically produce higher quality images of small organisms than cellular phones, making them the preferable option. However, cellular phone cameras can produce good quality, identifiable images when used correctly and carefully.

(iv) **Take multiple pictures of relevant structures at multiple magnifications from all angles.** Multiple pictures are often required to capture all relevant identifying structures of an organism. This usually includes a picture of the entire individual from a distance, and multiple close-up shots of reproductive structures from different angles. It can also include pictures of the lower surface, or other parts that are not visible without getting close to and adjusting the species.

(v) **Record what the species is growing on or in.** Many lichens and other fungi grow only on or in specific places. For instance, they may only occur on one species of tree, or only on calcareous rock. Substrate information is just as important as the species' macromorphology, and many species cannot be accurately identified without it.

(vi) **Include microscope images and chemical tests.** Many lichens, and other groups of organisms, cannot be identified without examining microscopic characters or conducting chemical tests (e.g., ascospores or photobionts). Without these data, some species cannot be identified. Thus, it is essential to include images of microscopic characters, which can easily be achieved by taking cell phone photographs through the eyepiece of a microscope. The results of chemical tests can also be documented with photographs.

(vii) **Add an extensive notes section.** For many lichen observations to be identifiable, there must be several items documented in the notes section. Key items include substrate, habitat, descriptions of characters that cannot be captured in a photograph, measurements of microscopic characters (e.g., spores), and the results of chemical tests. There is no word limit in the notes section on iNaturalist, so this section can be substantial as required.

(viii) **Limit the amount of disturbance.** One of the nice features of iNaturalist is the lack of disturbance to

Table 4. Research grade observations on iNaturalist of all lichens with a federal status rank in Canada and the USA.

Species	Status rank(s)	No. of research grade observations	No. and % of research grade observation correctly identified
Anzia colpodes	Threatened in Canada	22	20 (91%)
Cetradonia linearis	Endangered in USA, Vulnerable globally on IUCN Red List	15	15 (100%)
Cladonia perforata	Endangered in USA, Endangered globally on IUCN Red List	18	18 (100%)
Collema coniophilum	Threatened in Canada	0	0
Pectenia plumbea	Special Concern in Canada	50 checked of 373 posted	48 (96%)
Erioderma mollissimum	Endangered in Canada	19	18 (95%)
Erioderma pedicellatum	Atlantic population is Endangered in Canada	19	17 (89%)
Heterodermia sitchensis	Endangered in Canada	2	2 (100%)
Hypogymnia heterophylla	Threatened in Canada	31	3 (10%)
Leptogium platynum	Endangered in Canada	13	0 (0%)
Leptogium rivulare	Special Concern in Canada, Near Threatened globally on IUCN Red List	30	3 (10%)
Nephroma occultum	Threatened in Canada	3	3 (100%)
Pannaria lurida	Threatened in Canada	60	44 (73%)
Physconia subpallida	Endangered in Canada	50 checked of 70 posted	50 (100%)
Pseudocyphellaria rainierensis	Special Concern in Canada	46	40 (87%)
Sclerophora peronella	Atlantic population is Special Concern in Canada	10	3 (30%)
Scytinium polycarpum	Special Concern in Canada	14	4 (29%)

Note: National status ranks are provided along with global ranks issued by the International Union for the Conservation of Nature (IUCN).

wildlife by taking pictures only. Unfortunately, this limits the ability to identify many lichens. We recommend that collections not be made simply for the sake of applying name. Family or genus level identifications can still be made without disturbing the individuals. When species names are required (e.g., for research or inventories), disturbance can be limited by performing chemical spot tests in the field on a minute section of an individual and viewing it with a hand lens or a small handheld UV light at night. If the collection of some material is required to identify the specimen, limit it to a very small amount, such as one to two fruiting bodies only to examine the ascospores or one to two lobes for chemical analyses. If larger collections are made, we recommend depositing them in a herbarium so that the voucher is available for future study. Keep in mind that any collecting requires a permit in parks, conservation areas, or on private land.

(ix) **Avoid immature individuals.** If an individual is very small, unhealthy, or is missing important morphological characters, it often cannot be reliably identified. Thus, it is best to avoid posting observations of immature individuals.

(x) **Obscure locality data for rare species.** To avoid potentially drawing unwanted attention to rare species, obscure the locality data. iNaturalist will automatically obscure the locality data of rare species that have a status rank on the platform, but for species that do not have a rank, it must be done manually.

(xii) **Limit reliance on machine generated identifications.** While this function works well for some groups of organisms, it does not work well for many lichen species, particularly those that require microscopy or chemical analyses. This function can perpetuate errors and should be used with caution.

Commenting on observations

Identification of lichen observations must be confirmed by other iNaturalist users before they are designated as research grade and aggregated by the GBIF. Once an observation is on GBIF it can be downloaded and used for research or to make conservation decisions. Thus, it is essential that observation identifications are not confirmed by users unless they are sure of the species. There are a few best practices to follow to ensure the quality of the data being generated through iNaturalist and used worldwide.

(i) **Do not identify species posted without the required identification characteristics.** If all the characters required for accurate identification are not documented in an observation, then do not submit an identification. Any suggested names on such posts are only best guesses. Instead, a message can be sent to the user who made the observation asking for additional characters.

(ii) **Submit a comment without providing a species name if you are not sure of an identification.** Possible

species names can be suggested through a comment rather than as an identification if the species is not clear or if key characters are missing. By doing this, the number of erroneous research grade observations produced will be reduced and, consequently, aggregated by GBIF.

(iii) **Communicate why different names are suggested when there is disagreement with the identification.** If different identification is suggested using the 'Suggest ID' option, communicate why it is a particular species in the 'Tell us why' box. This way, the observer can assess whether the reasons for the new name are correct. Without providing reasons or evidence for alternate identifications, it is impossible to determine which name is correct among multiple suggestions.

(iv) **If using the 'Agree' option on a previous user's identification, also leave a comment describing why an identification is agreed with.** If an explanation is provided for why an observation is a particular species, then key characters are documented and other users can more fully assess the names suggested. Do not simply confirm names because a particular user already suggested it or because the name might be correct. Only two identifications are needed to produce a research grade observation; thus, it is important to be thoughtful when making identification confirmations and document the reasoning that the confirmation is based on.

Conclusion

Publicly available biodiversity data are quickly growing online due to the digitization of museum collections, platforms where anyone can create data (e.g., iNaturalist and eBird), and aggregate databases such as the Consortium of North American Lichen Herbaria (CNALH 2021), the Canadian Biodiversity Information Facility (CBIF 2021), and the GBIF (GBIF 2021). As these data sources grow, they become an increasingly powerful tool, which is one of the reasons why sound data quality is essential. Data quality guidelines exist in many other fields including business (SEC 2019), GIS (Zhang and Goodchild 2002), remote sensing (Lunette and Lyon 2004), and medicine (Gad and Taulbee 1996), but they are not as well developed for generating biodiversity data, particularly for taxonomically difficult taxa such as lichens.

Curators currently manage lichen observations posted on iNaturalist; however, they are limited by the information provided by observers. If details about chemistry or microscopic morphology are absent, observations cannot be revised accurately. Curators are also limited by the scope of their own expertise, i.e., no one has expertise in all areas of lichen taxonomy. One way to address this limitation and improve data quality is to occasionally have subject specialists curate species or genera in which they have expertise. This could be done by request as a scientific service or, if funds are available, they could be hired to periodically review observations. The machine learning for species recognition in iNaturalist will not solve these limitations and it can perpetuate errors.

Another limitation for observers interested in doing chemical and microscopic analyses on lichens is access to the required chemicals and equipment. However, there is no way around these obstacles to accurately identify many lichen species. If these tests cannot be performed, a solution is to leave observations at the genus or group level. For example, the *Cladonia chlorophaea* (Flörke ex Sommerf.) Spreng. complex or aggregate contains many species that differ chemically, but they cannot be distinguished morphologically (Brodo et al. 2001). There is an option in iNaturalist to place observations in *Cladonia chlorophaea* or in the *Cladonia chlorophaea* aggregate. Without chemical tests, they can only confidently be placed in the aggregate option.

Baseline information created by observations in iNaturalist improves our understanding of species' distributions and frequencies in space and time. This knowledge is increasing at a crucial time, when global biodiversity is rapidly declining (IPBES 2019). These data can be used to monitor changes in populations, inform conservation planning, and they can contribute valuable information to taxonomic revisions, phylogenetic analyses, and ecological modelling. However, reliable data are required for them to be used in these ways (e.g., Sutherland et al. 2004). By following our recommendations, future data produced in iNaturalist will be more accurate for lichens and other taxonomically difficult taxa.

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AQ5

AUTHOR QUERIES

Please answer all queries requiring corrections. Those left unanswered will be assumed to be correct.

AQ1: Please confirm all author names and affiliations.

AQ2: 'GBIF 2020' has been changed to 'GBIF 2021' to match the reference list. Please verify.

AQ3: Scientific names and authority information confirmed throughout with MycoBank.

AQ4: Please confirm changes to sentence beginning "Of the rare lichen observations examined. . .".

AQ5: The year published has been updated to reflect the year published in print. Please verify (https://www.tandfonline.com/doi/full/10.1080/00219266.2020.1739114).

AQ6: Please review all figures and figure captions for potential conversion errors (missing symbols) as well as issues related to size and contrast.

AQ7: Please review Tables 1 to 4 to ensure all data are present and formatted correctly.