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The importance of taxonomy for determining species distribution: a case study using the disjunct lichen *Brodoa oroarctica*

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Abstract

Species-focused conservation requires a thorough understanding of species' distributions. Delineating a species' distribution requires taxonomic knowledge and adequate occurrence data. For plants and fungi, herbaria represent a valuable source of large-scale occurrence data. Advances in digital technology mean that data from many herbarium collections worldwide are now easily accessible. However, species concepts can change over time requiring herbarium records to be re-examined and databases updated, which does not always occur synchronously across all collections. Therefore, non-critical use of these data can promote inaccuracies in understanding species distributions. Taxonomic revisions are common in understudied organisms, such as lichens. Here, we illustrate how changing taxonomy and non-critical acceptance of online data affects our understanding of disjunct distributions, using the lichen *Brodoa oroarctica* (Krog) Goward as an example. Defining the distribution of the arctic lichen *B. oroarctica* is confounded by changing taxonomy and uncertainty of herbarium records that pre-date taxonomic revisions. We review the distribution of this species in the literature and in aggregate occurrence databases, and verify herbarium specimens that represent disjunct occurrences in eastern North America to present an updated account of its distribution and frequency in eastern North America. We show that knowledge of changing species taxonomy is essential to depicting accurate species distributions.

Key words: aggregated datasets, occurrence data, Arctic–alpine affinity, collections-based research, GBIF, CLH

Introduction

A key component of species-focused conservation is a sound understanding of spatial distribution. This is especially important considering assessments of species-at-risk frequently include extent of occurrence (EOO) and area of occupancy as criteria (IUCN 2012; COSEWIC 2021). Status assessors base the delineation of EOO on aggregated occurrence data to create distribution maps. Investments in the digitization of natural history collections have facilitated the compilation of species occurrence records into online databases (e.g., the Global Biodiversity Information Facility (GBIF) and the Consortium of Lichen Herbaria (CLH); Consortium of Lichen Herbaria 2023; Global Biodiversity Information Facility 2023), which can easily be queried by researchers to address a range of questions (Lavoie 2013; James et al. 2018; Jackowiak et al. 2022; Saran et al. 2022). However, there is often more to each line in a database or dot on a map. Many occurrence records are supported by a voucher specimen in a museum with a collector, determiner, and a story (Johnson et al. 2023).

A close examination of natural history specimens can reveal important information from a conservation perspective (Lavoie 2013; James et al. 2018). For example, researchers have used herbarium records to document changing distributions and shifts in phenology (Lavoie 2013). However, it is also important to consider shifting taxonomy, particularly for understudied groups. When taxonomy changes, or is ambiguous, distribution maps may need to be adjusted and, in some cases, this can have important conservation implications. For example, Meredith et al. (2019) examined how ambiguous taxonomic resolution in macroinvertebrates affected estimates of species richness, abundance, and distribution using field-collected data from Lake Superior. Their focus was on datasets where some specimens were identified to genus, and others to species, without resolving the fact that some of these may be duplicates, owing to factors of specimen condition, maturity, or identifier expertise affecting the resolution of the identification.

When incorporating herbarium records into distribution data, care is particularly important when using older specimens. The species resolution, technology, and literature available to determiners in the past may have been considerably different than for modern researchers. New taxonomic tools have led to earlier species concepts being reclas-

Table 1. Chemistry, morphology, and distribution of the genus *Brodoa*, as described by Krog (1974).

Species name	Chemistry*				Spot tests		Morphology	Geography
	Phy	Atr	Fum	Pro	Medulla	Cortex		
Brodoa oroarctica	+	+	–	+/–	KOH−, C−, KC + r, PD− or + o	KOH + y	Thallus loosely attached and irregularly spreading; lobes knobby/pinched. Apothecia rare	Circumpolar, in North America extends down the Rocky Mountains, and disjunct in eastern North America
Brodoa atrofusca	+	+	–	+	KOH−, C−, KC + r, PD + o	KOH + y	Thallus adnate, in large round patches. Apothecia common	Central European mountains (Alps and Carpathians) and Pyrenées
Brodoa intestiniformis	–	+	+	–	KOH−, C−, KC−, PD + o	KOH + y	Thallus loosely attached, in round or irregular patches; abundant, flattened lobules near the centre and lobes adnate at margins. Apothecia common	Widespread in Europe between northern Scandinavia and the Mediterranean, and in high elevation, alpine habitats from the United Kingdom to the Balkans

*Phy = physodic acid, Atr = atranorin, Fum = fumarprotocetraric acid, Pro = protocetraric acid.

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sified (e.g., Sipman and Aptroot 2001; Onuţ-Brännström et al. 2017; Boluda et al. 2019). Thus, when using older specimen data, particularly from species that have had multiple taxonomic revisions, careful consideration is needed before incorporating label data. Ideally, researchers will review these specimens prior to their inclusion in a study. Lichens are a group of taxonomically difficult species that have received considerable revision in recent decades. For example, the use of chemical analysis in lichen systematics aided in describing new species in North America, in particular those with extremely narrow morphological differences to European taxa (Culberson 1969). Circumscription of taxa in the genus *Cetraria* Ach. was altered significantly through examination of ascus structure (Kärnefelt et al. 1993); that study resulted in the description of two new genera, *Arctocetraria* Kärnef. & Thell and *Cetrariella* Kärnef. & Thell, as well as multiple new species combinations. Molecular analysis is yet another tool used to propose taxonomic revisions, particularly where other characters may not appear consistent, for example in the genus *Thamnolia* Ach. ex Schaerer. (Onuţ-Brännström et al. 2018). In some cases, digitization of collections simplifies updating specimen nomenclature in response to these taxonomic changes. However, misapplied nomenclatural annotations, where synonymies are applied without re-examining a specimen, can create data issues in the wake of taxonomic revisions (Allen et al. 2019).

Taxonomy is the underlying unit of biodiversity research, particularly in relation to delineating species' ranges. Understanding the details of a species' range can reveal valuable insights into its life history, including the ecological mechanisms that drive dispersal, establishment, and persistence across a landscape. Of particular interest in ecology are disjunct populations (where a species' range is not continuous), which often warrant conservation attention because of their rarity in a particular area; for example, the rare orchid *Cypripedium passerinum* Richardson, which has a disjunct population on the north shore of Lake Superior (Irvine and Patterson 2022) or the multiple rare species in the southern Appalachians (Manos and Meireles 2015). On the island of Newfoundland, Canada, the provincial government established the Hawke Hills Ecological Reserve (47.32N, −53.12W, ∼300 m elev.) explicitly to conserve disjunct populations of Arctic–alpine species of plants, notably *Diapensia lapponica* L. (Government of Newfoundland and Labrador 2006). Lichens restricted to Arctic–alpine environments in North America are often distributed across the Arctic and down the Rocky Mountains, but they can also occur disjunct elsewhere (Brodo et al. 2001; McMullin and Dorin 2016). Identifying these areas and populations of conservation concern relies on up-to-date taxonomy and accurate identifications. Herein, we provide a case study that illustrates the importance of reliable identifications using a disjunct population of the lichen *Brodoa oroarctica* (Krog) Goward ("the Arctic sausage lichen") on the island of Newfoundland.

Case study of *Brodoa oroarctica*

Taxonomy

Krog (1974) studied the chemistry, morphology, and geography (Table 1) of the *Hypogymnia intestiniformis* complex in Alaska, Norway, and the Alps, additionally examining vouchers from major Norwegian herbaria. During this process, she recognized a new, third species within the complex (formerly composed of *Hypogymnia atrofusca* (Schaer.) Räs. and *Hypogymnia intestiniformis* (Vill.) Räs.) and called it *Hypogymnia oroarctica* Krog. Goward (1986) then proposed a new genus, *Brodoa*, to represent the three species in this complex. Here, we use the currently accepted names—*Brodoa atrofusca* (Schaer.) Goward, *Brodoa intestiniformis* (Vill.) Goward, and *B. oroarctica*.

Brodoa oroarctica is a foliose, dark grey, saxicolous lichen (Fig. 1A), and is the only member of this complex known to occur in North America (Krog 1974). Krog (1974) described *B. oroarctica* as having atranorin (KOH+ yellow) in the cortex, physodic acid (KC+ red) in the medulla, and occasionally protocetraric acid (PD−/+ orange; near the lobe tips), while the similar *B. atrofusca* always contains protocetraric acid (PD+ orange) and differs in its thallus growth pattern (forming rosettes vs. the irregular spreading thalli of *B. oroarctica*), and *B. intestiniformis* lacks physodic acid (KC−) but contains fumarprotocetraric acid (PD+ orange) (Table 1). Ohlsson

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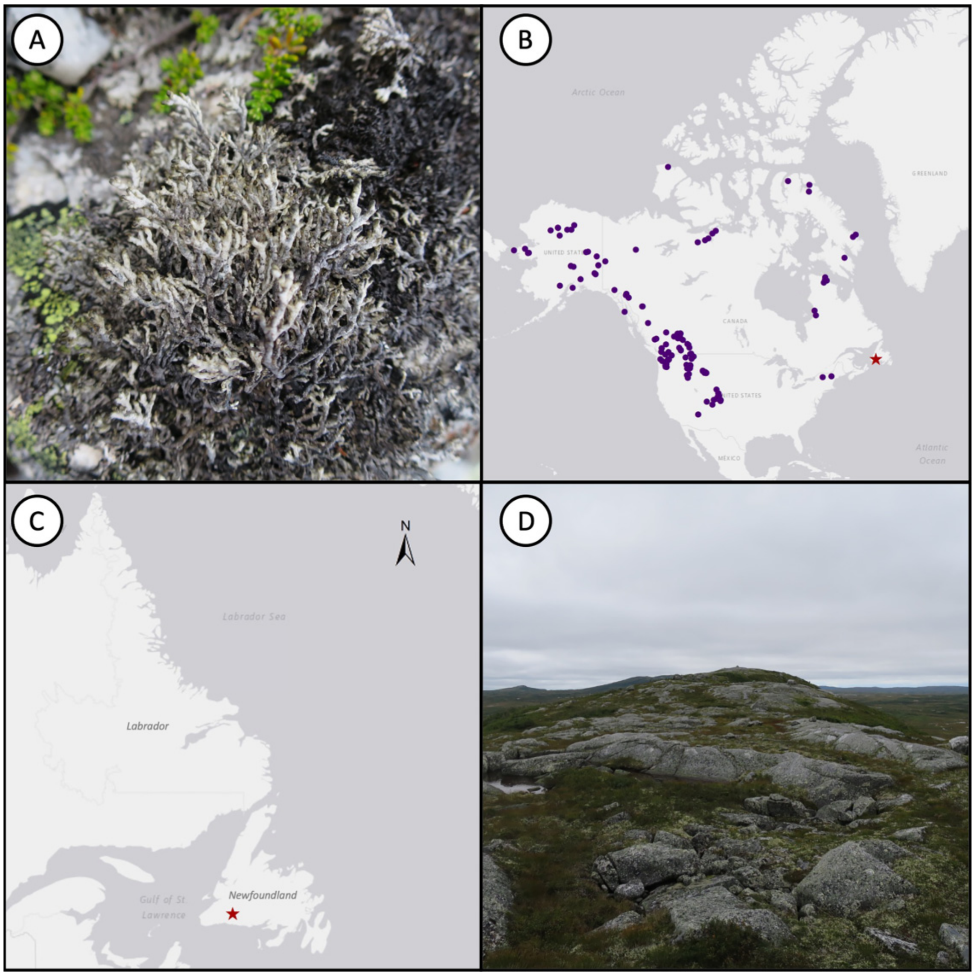
Fig. 1. Morphology, habitat, and distribution of *Brodoa oroarctica* in North America. (A) *Brodoa oroarctica* thallus in situ, South Coast Division, Newfoundland and Labrador, Canada, (B) North American distribution of *B. oroarctica* after updates and review of specimens as described in this study, (C) geographic location of *B. oroarctica* occurrence on the island of Newfoundland, and (D) Arctic–alpine barrens landscape at *B. oroarctica* occurrence on the island of Newfoundland. We created the maps in 1B and 1C using ArcMap (version 10.8.1; ESRI 2010) and the basemap "Light Gray Canvas Map" (ESRI 2021) with species occurrence data from Global Biodiversity Information Facility and Consortium of Lichen Herbaria (GBIF.org 2022; lichenportal.org 2022).



(1973) examined *Hypogymnia* (Nyl.) Nyl. in North America, including vouchers he determined as *H. atrofusca*. Through thin-layer chromatography (TLC) and chemical spot tests, he reported that all the North American material he determined as *H. atrofusca* appeared to be PD−, containing only atranorin and physodic acid. For this reason, it appears Krog (1974) recognized Ohlsson's *H. atrofusca* determinations for North American material as *B. oroarctica*, in particular citing Ohlsson (1973) for two disjunct occurrences in eastern North America.

Distribution

While all three *Brodoa* species have Arctic–alpine affinities (Goward 1986), only *B. oroarctica* is known from North America; *B. atrofusca* and *B. intestiniformis* are restricted to Europe (Krog 1974). *Brodoa oroarctica* is circumpolar, including the Rocky Mountains in western North America and alpine areas of the Scandinavian Peninsula in Europe (Ohlsson 1973; Krog 1974). *Brodoa intestiniformis* and *B. atrofusca* are restricted to alpine habitats, the former widely distributed throughout Europe and the latter more restricted to the mountains of central Europe (e.g., the Alps and Carpathians; Krog 1974).

Outside the continuous circumpolar distribution of *B. oroarctica*, Krog (1974) cited Ohlsson (1973) for two disjunct records in eastern North America: both in the United States, one in the Adirondacks in New York state and one in the White Mountains in New Hampshire. Ohlsson's (1973) records have been accepted and cited in other texts (e.g., Thomson 1984; Brodo et al. 2001; Hinds and Hinds 2007); however, despite extensive lichenological work in eastern North America in the last few decades (e.g., Fryday 2006; Hinds et al. 2009; Allen and Lendemer 2016; Buck 2016; McMullin and Dorin 2016; McMullin et al. 2017; Tripp and Lendemer 2019; Tripp, Lendemer and McCain 2019), particularly in alpine habitats throughout the Appalachian Mountain range (i.e., appropriate habitat for *B. oroarctica*), there are no other published or digitally discoverable records of *B. oroarctica* disjunct in eastern North America. Further, in con-

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trast to the distribution cited by Krog (1974) and others, online databases that aggregate occurrence data (e.g., CLH and GBIF) have some occurrence records for the two European species in North America. Prior to the distribution updates we have documented through our investigation here, the eastern North America disjunction for *B. oroarctica* cited in the literature did not appear to match the online data.

The records of the European taxa in North America should be re-examined, as many voucher determinations pre-date Krog's (1974) treatment of this species complex. However, the apparently missing records for *B. oroarctica* in New York and New Hampshire in the online databases are puzzling. It is clear the occurrence records for this genus in North America are due for review using current taxonomic conventions and chemical analysis. For this reason, we focus on the records of *B. oroarctica* in eastern North America below the Arctic because the accuracy of these occurrences represents a large disjunction for this species and these vouchers do not appear to have been re-examined against Krog's (1974) description; we also include all available *Brodoa* vouchers from this region in our study, as specimens carrying the European species' names are likely misidentifications and potentially represent *B. oroarctica*.

Methods

Site description

Our study was initiated by the discovery of *B. oroarctica* in Newfoundland and Labrador, Canada by HP during fieldwork surveying lichens in Arctic–alpine barrens across the island of Newfoundland. The site where HP found this lichen is located in the South Coast Division of the province (48.010679N, −57.681368W; Fig. 1C). The barrens at this site are a granitic outcrop (Fig. 1D) and local high point (~520 m a.s.l.), surrounded more broadly by maritime barrens. It is ~60 km east of the Southern Long Range Mountains (an extension of the Appalachian Mountain Range, which runs north–south in continental eastern North America and up the west coast of Newfoundland; South 1983). Mesohabitats at the site are a mix of heath and exposed rock (including cobble and large glacial erratics), with scattered krummholz. Notable Arctic–alpine taxa also at this site include *D. lapponica, Thamnolia subuliformis* (Ehrh.) W.L. Culb., *Flavocetraria cucullata* (Bellardi) Kärnefelt & A. Thell, and *Flavocetraria nivalis* (L.) Kärnefelt & A. Thell.

Data sources and literature review

We conducted two searches each on CLH and GBIF: one for the species "*Brodoa oroarctica*" including synonyms and a second for the genus "*Brodoa*" including synonyms (GBIF.org 2022; lichenportal.org 2022). We excluded records from these searches for species from the genus *Allantoparmelia* (Vainio) Essl. because there is no published literature supporting that it is a clear synonym of any *Brodoa* species, and *Allantoparmelia* species produce different metabolites than those in *Brodoa* (Brodo et al. 2001; Esslinger 2019). We also searched Canadensys and the New York Botanical Garden databases; these sources did not add any new records. Beyond these online databases, we also reviewed salient literature on lichen taxonomy and biogeography for references to *B. oroarctica* and Arctic–alpine disjunctions in North America (e.g., Thomson 1984; Brodo et al. 2001; Fryday 2006; Hinds and Hinds 2007; Hinds et al. 2009; McMullin and Dorin 2016; Tripp and Lendemer 2019).

We contacted the herbaria mentioned in Ohlsson (1973) (Canadian Museum of Nature (CANL) and University of Michigan (MICH) in North America, and the National Museum of Nature and Science (TNS) in Japan) to locate vouchers of the reported disjunct occurrences of *B. oroarctica* in New Hampshire and New York. We contacted the Farlow Herbarium (FH) to locate the voucher for New Hampshire referenced in Hinds and Hinds (2007). We also contacted the Norwegian herbaria where Krog completed her work on this species complex: the Universities of Oslo (O) and Bergen (BG), and UiT the Arctic University of Norway (TROM), to check whether they had any relevant non-digitized collections from eastern North America. Additionally, we reached out to Drs. Irwin Brodo (CANL) and Alan Fryday at Michigan State University, and James Lendemer at the New York Botanical Garden (NY), lichenologists familiar with the North American taxa and the latter two specifically engaged in studying lichens in the Appalachians, to ask whether they have observed or collected this species disjunct in eastern North America.

We borrowed all available vouchers for *Brodoa* species in eastern North America below the Arctic and from the province of Newfoundland and Labrador. These collections were generously loaned for study by the Field Museum of Natural History (F), FH, MICH, Academy of Natural Sciences (PH), Smithsonian Institution (US), and University of Wisconsin (WIS). We also contacted the Herbier Louis-Marie at Université Laval (QFA) about two collections of *B. intestiniformis* in the province of Quebec recorded on bark (not a substrate listed for any *Brodoa* species); we did not borrow these specimens as Claude Roy (QFA) examined them and corrected the determinations to *Parmelia sulcata* Taylor and *Parmeliopsis hyperopta* (Ach.) Arnold.

We used R studio (version 4.2.2; R Core Team 2022) to combine data from our searches and the vouchers examined into a single dataset and removed duplicates (based on catalog number) and records that did not have a catalog number, latitude, or longitude. We used the R package "CoordinateCleaner" (version 2.0-20; Zizka et al. 2019) to flag and remove potentially spurious records, including those located at the centroid of a geopolitical unit, in water, or at the GBIF headquarters, as well as records with problematic coordinates (e.g., zero coordinates, identical latitude and longitude, or likely decimal conversion errors). We used ArcMap (version 10.8.1; ESRI 2010) to create the maps presented in Fig. 1.

Identification

We examined the morphology of 13 collections, including the collection made during fieldwork on the island of Newfoundland, against Krog's (1974) descriptions and other salient lichen literature (e.g., Thomson 1984; Brodo et al. 2001; Hinds and Hinds 2007) using standard light microscopy and chemical spot tests with C (10% sodium

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hypochlorite), KOH (10% potassium hydroxide), and PD (para-phenylenediamine crystals dissolved in 95% ethanol). We conducted TLC on collections as needed, following the methods of Culberson and Kristinsson (1970) and Orange et al. (2010), using glass TLC silca gel 60 F254 plates in solvents A, B′, and C. HP's collection is housed at CANL in Gatineau, Quebec.

Results

Of the existing six unique, disjunct records for *B. oroarctica* we found for North America, two were misidentified and four were filed under outdated names (*H. atrofusca* and *Parmelia encausta* (Sm.) Nyl.). Through re-examination of these six vouchers, we confirm that *B. oroarctica* is disjunct in the White Mountains of New Hampshire and the Adirondacks of New York, as noted across the literature (e.g., Krog 1974; Brodo et al. 2001; Hinds and Hinds 2007; Fig. 1B). However, the occurrence vouchers from Labrador are misidentifications. Further, we identify a previously unpublished occurrence in the province of Quebec, Canada that is potentially disjunct; however, the exact location of this record is unclear (see Annotated Species List S1: voucher from Poulin #17068-b, MICH105940). We investigated a further eight disjunct records in North America that we found during our wider search for *Brodoa*. These were filed as *B. intestiniformis*, all collections were misidentified and are not from the genus, *Brodoa*.

Brodoa oroarctica (Krog) Goward

Description: Morphologically, this species is characterized by narrow (0.5–1 mm wide), cylindrical branches that appear inflated but are solid; often loosely attached to substrate and spreading irregularly (vs. orbicularly, as in the chemically similar European species, *B. atrofusca*; Krog 1974). Chemically, it is distinct from its North American and European lookalikes (*Allantoparmelia alpicola* (Th. Fr.) Essl. has alectorialic and barbatolic acids, *Allantoparmelia almquistii* (Vainio) Essl. has olivetoric acid, and *B. intestiniformis* has atranorin and fumarprotocetraric acid) in producing atranorin (K+ pale yellow, cortex), physodic acid (KC+ pink, medulla), and sometimes protocetraric acid (PD+ orange, medulla; Brodo et al. 2001).

Ecology and distribution: We report the first verified record of this species for the province of Newfoundland and Labrador (two previous records from Labrador are misidentifications) and the most eastern occurrence of this lichen in North America. This lichen is also disjunct in New York and New Hampshire; however, these vouchers were determined as *H. atrofusca* and *P. encausta* prior to our study and had not been annotated to reflect assumptions made in the literature. Further, these records are from at least 90 years ago, and there are no newer vouchers or observations that we are aware of. There is a potential fourth disjunction in Quebec; we have included this voucher in the Annotated Species List (S1), but excluded it from our distribution map (Fig. 1B) due to the vague location information.

New specimen record: Canada. Newfoundland & Labrador. South Coast (Division No. 3). Arctic–alpine barrens above old quarry, on southwest side of NL-480, approx. 100 km south from Trans-Canada Highway. Elev. 520 m a.s.l. 27.XI.2022, saxicolous. TLC$^{CMN1706-10}$: atranorin, physodic acid, +unknown. H. Paquette 2736 (to be deposited at CANL). Det.: H. Paquette (2022), Ver.: J. McCarthy (2022), R.T. McMullin (2023).

Discussion

The disjunction of *B. oroarctica* in eastern North America appears limited, with only four verified occurrences: in New Hampshire (2) and New York (1) (the White Mountains and Adirondacks, respectively) and in Canada on the island of Newfoundland (1). There is a potential fifth disjunction in the province of Quebec; however, the location of that occurrence is unclear.

The occurrences of *B. oroarctica* in eastern North America that Krog (1974) cited from Ohlsson (1973) are supported by vouchers at MICH originally named *P. encausta* and annotated to *H. atrofusca* by Ohlsson in 1972 (note: Ohlsson does not identify these vouchers in his 1973 paper; however, the locality information and his annotations align with the information he presented in that paper). All literature references to the *B. oroarctica* disjunction in eastern North America can be traced back to Ohlsson (1973) (e.g., Krog 1974; Brodo et al. 2001; Hinds and Hinds 2007). We re-examined these collections, including using TLC analysis to verify chemistry, and confirmed Krog's (1974) assessment that they are *B. oroarctica*. Ohlsson annotated a third voucher of *H. atrofusca* in eastern North America from the province of Quebec but did not include this location on his map or mention it in his paper. The location of this collection is given as "McGill Lake, QC" on the packet label. There are four McGill lakes ("Lac McGill") identified by the Canadian Geographical Names Database: in the MRCs of Le Haut-Saint-François, Montcalm, and Antoine-Labelle; and the unorganized territory of Rivière–Koksoak (Government of Canada 2021). Three of these locations are within 200 km of the island of Montreal (i.e., truly disjunct from the Arctic), while the fourth (Rivière–Koksoak) is part of the Ungava Peninsula in northern Quebec (i.e., Arctic). There are no published accounts of this species in Quebec, outside of the Arctic, and this collection is from 1946 and the only record for this lichen this far south in the province of Quebec: for these reasons, we have not included it on our distribution map (Fig. 1B).

Hinds and Hinds (2007) referenced a second voucher from the White Mountains in New Hampshire located at FH; it was filed as *P. encausta*, a determination made by Edward Tuckerman in the 1880s. We examined this collection, ran TLC to confirm its chemistry and annotated it to *B. oroarctica*.

In Newfoundland and Labrador, we found two records in the CLH database of *B. oroarctica* (from US and WIS) both from Labrador. These collections were determined prior to Krog's (1974) treatment and are misidentifications. Based on morphology and TLC analysis, we determined these collections to be *A. almquistii* and *A. alpicola*. Therefore, we report the first verified record of this species in the province.

In the genus *Brodoa* more broadly, we found eight additional North American collections of interest at F from New Hampshire (1) and North Carolina (2), and at PH and QFA

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from Newfoundland and Labrador (2) and Quebec (3). These collections pre-date Krog's (1974) treatment and are filed as *B. intestiniformis* (a species not known from North America). The determinations for these collections were either an outdated name (five vouchers; labelled *P. encausta*) and were filed as *B. intestiniformis* due to synonymy, or had a nomenclatural annotation applied but do not appear to have been re-examined (three vouchers; labelled *B. intestiniformis*). Additionally, most of these collections (7) were from bark, a substrate not known for *Brodoa*. We found that all were misidentified and instead represent species from the genera *Hypogymnia*, *Hypotrachyna* (Vanio) Hale, *Parmelia* Ach., *Parmelinopsis* Nyl., and one unknown but suspected to be in the genus *Allantoparmelia*.

Delineating species' distributions accurately is important for conservation initiatives. For example, defining the distribution of a species is critical to understanding its rarity and range size (Manzitto-Tripp et al. 2022), criteria imbedded in national and international conservation status assessments like those produced by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) and the International Union for the Conservation of Nature (IUCN) (IUCN 2012; COSEWIC 2021). Further, understanding the distribution and amount of genetic diversity within species' populations is a key element in developing conservation strategies (Provan and Maggs 2012).

Disjunct populations are of ecological and conservation consequences as these populations can represent unique genetic variation (Provan and Maggs 2012) and possible holdout or stepping stone populations that could contribute to the persistence of a species through climate change (Hannah et al. 2014). Therefore, characterizing species' distributions, particularly those with disjunctions, such as the lichen *B. oroarctica*, is important for evaluating rarity, genetic diversity, and ultimately understanding the extinction risk and conservation opportunities for disjunct populations. Confirming and documenting the disjunction of this lichen in particular contributes to our understanding of Arctic–alpine lichens and this unique pattern of disjunction in North America.

Discerning taxonomy is foundational to establishing distribution from myriad sources contributing to aggregate species occurrence data. Although global species occurrence data have never been more accessible due to online databases like GBIF and CLH species taxonomy is not static. When considering understudied, cryptic biota, non-critical use of these occurrence data can lead to misrepresenting species ranges. We have demonstrated this using *B. oroarctica* in North America, showing that digitally discoverable occurrence records representing its disjunction in eastern North America were misidentified and key vouchers cited in the literature had not been re-examined or annotated to reflect the most recent taxonomy. More broadly in the genus *Brodoa*, eight digitized records of *B. intestiniformis* appear in eastern North America despite peer-reviewed literature stating that that species is restricted to Europe (Krog 1974; Goward 1986). It is also notable that these records remained filed under out of date or otherwise illegitimate names almost 40 years after Krog's comprehensive treatment of this species complex; this underscores that digitization efforts do not equate to examination and annotation of collections by experienced individuals. Based on our findings for eastern North America disjunct records of *Brodoa*, Krog's (1974) work on this genus, and Esslinger's (2019) Cumulative Checklist of the Lichen-forming, Lichenicolous and Allied Fungi of the Continental United States and Canada, it is likely that any remaining North American records for *B. intestiniformis* or *B. atrofusca* are also misidentifications; however, to update the identities of these records, it is necessary to re-examine voucher specimens, particularly their chemistry.

Our experience studying *B. oroarctica* is not unique. Allen et al. (2019) highlighted misidentifications of historical lichen vouchers, specifically from nomenclatural updates, as a notable challenge to using aggregate occurrence data. Those authors stated that the data deficiencies in online databases resulting from these misidentifications and (or) misapplied names are overlooked, presenting the case of *Xanthoparmelia conspersa* (Ehrh. ex Ach.) Hale as an example of where changes to species circumscription requires physical re-examination of prior vouchers to accurately update the identities. Another example of this is in McMullin (2019), where the author found that for *Juella lactea* (A. Massal.) M.E. Barr in North America, less than half the herbarium collections examined were accurately identified. Taxonomy is foundational in ecology; it is the main unit by which we characterize species' ranges, their diversity or rarity across landscapes and within ecosystems. However, taxonomy is not fixed and therefore is a consideration in every study that uses species occurrence data to examine a hypothesis; this is especially salient for cryptic or understudied taxa where taxonomic concepts may be poorly defined or have a complicated history of revisions. Natural history collections are valuable, and in many instances irreplaceable, sources of species biogeographic data, particularly for plant, fungi, and lichen taxa. These collections require continued curation and re-examination to contribute accurate, meaningful data sets rooted in sound taxonomy. Researchers play a role in the maintenance of these collections through studying and annotating vouchers, as well as appropriately citing these data in their publications (i.e., attributing collection numbers and institutions, as we have done in the Annotated Species List S1).

Conclusion

Our study of *B. oroarctica* is an example of how thorough review of species occurrence data includes reviewing taxonomy and examining voucher specimens. We report that *B. oroarctica* is disjunct on the island of Newfoundland and at least historically disjunct in the White Mountains of New Hampshire and the Adirondack region of New York (vouchers from the 1880s and 1933, respectively). Further, outside of our record from Newfoundland, it appears that this lichen has not been recorded at a disjunct location in eastern North America (including in the vicinities of the vouchers we examined) in 90 years, despite active lichenological research throughout this region (pers. comm. I.M. Brodo, A. Fryday, J. Lendemer, and J. McCarthy 2023).

Despite the apparent simplicity of our results (i.e., four dots on a map), time and resources to carry out the necessary investigations of specimens was extensive and goes well be-

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yond the efforts of the authors. We corresponded with staff or volunteers at 11 different institutions (BG, F, FH, MICH, O, PH, QFA, TNS, TROM, US, and WIS) on three continents (Asia, Europe, and North America). We received loaned material from six of those institutions (F, FH, MICH, PH, US, and WIS), which involved locating physical specimens, examining non-digitized collections, international shipping, and collaboration with an additional local institution in St. John's, NL (NFM) to host loans for the first author. At the other five institutions, staff or volunteers searched collections, confirmed label details for vouchers, provided photographs of collections, created lists of non-digitally discoverable specimens, and in one case examined and re-determined vouchers of interest for the first author. This work by contributors beyond the authors and outside of our home institutions underpins all research where vouchered occurrence data are verified, a step we (and others; e.g., Lendemer 2015; Allen et al. 2019; McMullin 2019) have shown is critical to avoid the perpetuation of errors in future research that reaches well beyond studies specifically interested in taxonomic questions. We hope detailing our targeted investigation of the lichen *B. oroarctica* and discussing the broader consequences of uncritically employing occurrence data in ecological studies or for conservation decisions highlights the necessity for continued basic biodiversity research.

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Data availability

Data are available upon request.

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Competing interests

We declare there are no competing interests.

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Supplementary material

Supplementary data are available with the article at https://doi.org/10.1139/cjb-2023-0096.

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