CHAPTER 7

The National Lichen Atlas: Summarizing 23 Years of Epiphytic Lichen Community Data

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INTRODUCTION

Since its inception in 1989 to the present, nearly 10,000 standardized surveys of epiphytic (tree-dwelling) lichen communities have been conducted as part of the National Lichen Indicator ("Indicator" hereafter), making it the single most extensive lichen community monitoring program in the world. These surveys, used widely by Federal Land Managers (FLMs) and researchers alike, provide valuable information on air quality, climate, biodiversity, and lichen floristics in U.S. forests. Many surveys were conducted on the U.S. Department of Agriculture, Forest Service, Forest Inventory and Analysis (FIA) plot network and thus link to numerous co-located measurements of forest structure collected by FIA field crews. Moreover, the systematic nature of the data, which also provides information about where lichen species *do not* occur, is highly valuable to ecologists, biogeographers, and taxonomists seeking to understand species' distributions and habitat preferences.

Three Forest Service programs played central roles in collecting Indicator data. The earliest surveys collected in the late 1980s were part of various pilot studies conducted "off grid" by the Forest Health Monitoring (FHM) program and the National Forest System's Air Resource Management (ARM) program. In 1993, the FHM program initiated large-scale data collection on the FIA grid (Stolte and others 1993), with the FIA program taking over management of the Indicator around 2003. The ARM program, using their own funding, field crews, and sampling schedule, also conducts many of their surveys on the FIA plot network.

Field and data processing protocols were consistent across participating programs. However, the format of collected data, its accessibility, taxonomic treatment of lichen species, and the availability of other co-located datasets, varied widely. Thus, our goal was to package together Indicator data across parent programs, for the first time, using a consistent, user-friendly format. To do so, we built a comprehensive database called the National FIA Lichen Database (NFLD) and used it to create a National Lichen Atlas to illustrate the breadth of the combined Indicator datasets (Jovan and others 2020, 2021b). These products cover the first 23 years of Indicator data, up through 2012 when FIA ceased large-scale collection of lichen surveys. Data collection since then has been more sporadic and geographically targeted, often using the 23 years of data in the NFLD as a baseline.

METHODS

Field

In brief, Indicator data come from timed surveys (up to 2 hours) aiming to capture all epiphytic noncrustose lichen species encountered within a 0.94-acre area. A voucher specimen is collected and abundance code assigned to every species suspected to be unique (Jovan and others 2020). Surveyors are specially trained and certified in the Indicator protocol, with their performance assessed by professional lichenologists usually at least once per season. Voucher specimens are identified by lichenologists and later deposited in herbaria to make them available for further study.

Data

For the NFLD, we built six linkable core tables to house all FHM and FIA data using a structure similar to the "LICHEN-…" tables in the Forest Inventory and Analysis Database (FIADB), one of several parent databases to the NFLD. We integrated all ARM data collected through 2012 into a seventh table, [LICHEN_ATLAS], which we used to generate the species distribution maps for the National Lichen Atlas. The [LICHEN_ATLAS] table serves as a user-friendly starting place for analysts because it integrates all data, including relevant geographic and the most commonly used environmental variables, into a single table. For more information, the NFLD version 1.0 is available along with a detailed user guide (Jovan and others 2020) at https://www.fia.fs.usda.gov/program-features/indicators/lichen/.

RESULTS AND DISCUSSION

For the comprehensive [LICHEN_ATLAS] table, we were able to collate approximately 115,500 lichen records across the three participating Forest Service programs. Records represent about 8,300 lichen community surveys covering 6,000 unique forested locations from 1989 to 2012 (fig. 7.1). The NFLD makes more than one-third of these Indicator surveys available to the public for the first time. The FHM program collected 2,311 surveys; FIA collected an additional 3,061; ARM added an additional 2,970 surveys to [LICHEN_ATLAS] over the same time period.

More than 85 percent of all surveys were collected on the FIA grid (and are identified as such in the NFLD), which means extensive co-located forest structure data may be available for these plots. The user guide (Jovan and others 2020) provides instructions for accessing the NFLD's parent databases to help users obtain environmental variables not included in the [LICHEN_ATLAS] table. The remaining surveys, classified as "off-grid" plots, were located in areas of special interest to support specific research or management objectives not otherwise served by the on-grid dataset. Requests for additional data for off-grid sites can be sent to this chapter's authors.

Indicator surveys detected roughly 440 distinct taxa as identified under program criteria. The evolutionary history of lichens is poorly understood compared to vascular plants, making the field of lichen taxonomy highly dynamic. Thus, to compare "apples to apples," users of Indicator data must first assess the need to reconcile the taxonomy of lichen names in their dataset. More than 350 taxonomic name changes were adopted by the Indicator programs over the course of data collection. Each change in name or species concept is recorded in the core NFLD table named [REF_LICHEN_SPP_COMMENTS]. This table provides detailed rationales for each name change, along with relevant literature citations and suggested actions for users to take depending upon the geographic region and timespan their dataset covers. Alternatively, we have already applied a consistent taxonomic treatment to the [LICHEN_ATLAS] table, making it a user-friendly starting point with the main downside being that we needed to lump a few cryptic species and several newer species

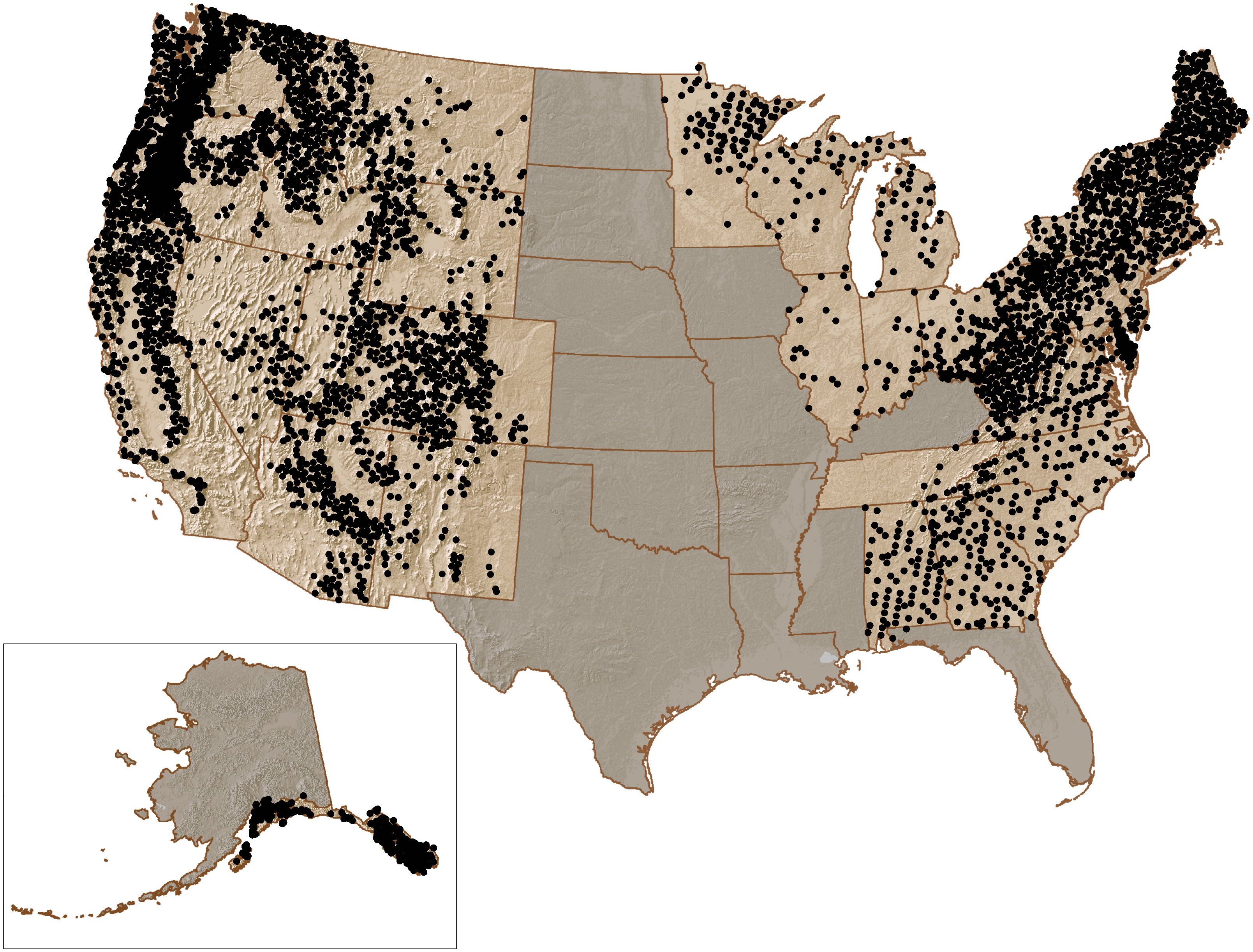


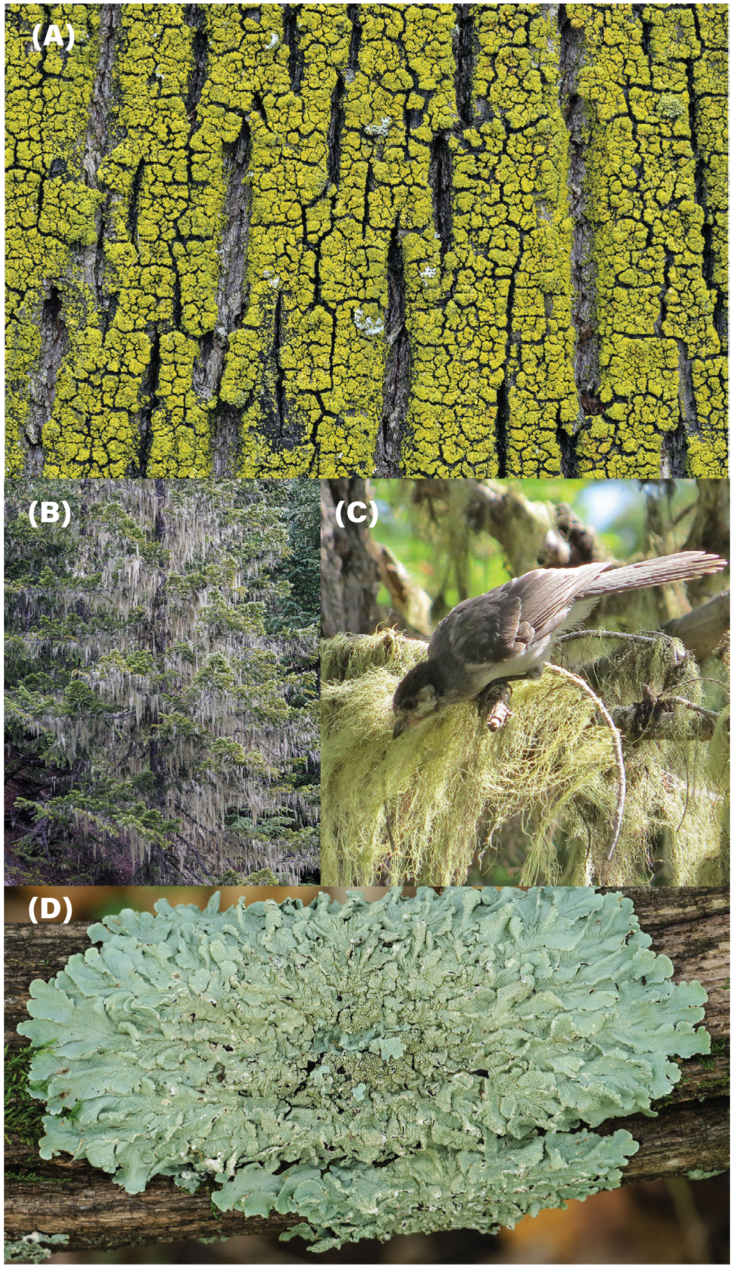
Figure 7.1—Map of lichen survey sites in the National Lichen Atlas (Jovan and others 2021b). Each site was visited one to four times. Site locations are approximate.

names together due to the long time period covered by the dataset. Older specimens are not routinely revisited to update species names although many are stored in herbaria and thus available to interested users for further study. This left us with about 400 taxa to feature with distribution maps and photos in the Atlas. The [LICHEN_ATLAS] table includes both the reconciled and original names determined for each lichen occurrence, so analysts wishing to use the table can make their own decisions about when and how to implement suggested actions in [REF_LICHEN_SPP_COMMENTS].

Atlas Examples: Distributions of Air Quality Indicator Species

More than 100 studies to date use the Indicator data as a baseline for investigating spatial and, increasingly, temporal trends in lichen community-based metrics (Jovan and others 2020). Many metrics have been developed to indicate air quality, climate, and other change on forest land in the United States, although air quality is by far the most common focus. Lichens are highly sensitive to pollution due to their reliance on atmospheric sources of water and nutrients, leading to the accumulation of many pollutants in their tissues as well as predictable shifts in species composition. Metrics describing these community shifts and assays measuring pollutant concentrations in lichen tissue are both common, inexpensive ways to better understand pollution patterns across the landscape.

For example, excess nitrogen (N) deposition is linked to a wide array of detrimental ecological effects in both the Eastern and Western United States (Jovan and others 2021a, Root and others 2021, Smith and others 2020). Lichens are extremely responsive to N; as levels begin exceeding natural background levels, lichen communities start to gain "eutrophic" (i.e., N-loving) species and lose native "oligotrophic" (N-sensitive) species. Eutrophs, like species of the brightly colored genera *Candelaria* (figs. 7.2A and 7.3), *Xanthoria,* and *Xanthomendoza*, tend to be relatively small in size with broad geographic distributions. Eutrophs occur in naturally N-enriched sites (e.g., under bird perches), although anthropogenic N sources like fertilizers, livestock enclosures, and motor vehicle emissions have allowed them to greatly expand their abundance. In contrast, oligotrophs may grow quite large, play important ecological roles in the forest system, and often have geographically restricted distributions even in the absence of pollution. One example, the iconic witch's hair lichen (*Alectoria sarmentosa*; figs. 7.2B, 7.2C, and fig. 7.4), grows abundantly on tree trunks and branches in wet montane forests of the Northwest and Alaska where it is used extensively by wildlife for forage and nest building. Ecological functions like these are thus impacted when elevated N reduces the health and abundance of *A. sarmentosa* and other oligotrophic species. Community shifts like this, i.e., where sensitive species are replaced by tolerant or pollution-loving species, are the basis of lichen-based "critical loads," a management tool FLMs use to determine where pollutant levels may be causing ecological harm (Geiser and others 2021).



Other pollutants, like heavy metals and many air toxics, accumulate in lichens without causing observable community-level effects. The ARM program, which is most active in the Pacific Northwest and Alaska, pairs all Indicator community surveys with assays of heavy metals, N, and sulphur (S) in lichen tissue collected onsite. Witch's hair lichen (figs. 7.2B and 7.2C) grows in long luxurious "beards," making it a favorite target species of ARM surveyors. Tissue collection by FIA crews was never a routine part of the 23 years of "baseline" data, although most recent surveys include some assay data. One of the most common target species collected on FIA plots in the East, for instance, is the common greenshield lichen (*Flavoparmelia caperata*; figs. 7.2D and 7.5), valued for its widespread distribution and manageable size (Will-Wolf and others 2017).

Figure 7.2—Photos of common lichens used to indicate air quality: (A) Candelaria pacifica*, (B, C)* Alectoria sarmentosa*, and (D)* Flavoparmelia caperata*. (A, B, D: Courtesy photos by Richard Droker [Creative Commons license: https://creativecommons.org/licenses/by-nc-nd/2.0/]; C: Courtesy photo by Leppyone [Creative Commons license: https://creativecommons.org/licenses/by/2.0/])*

Lemon lichen
Candelaria concolor/pacfica (Dicks.) Stein/M. Westb. & Arup

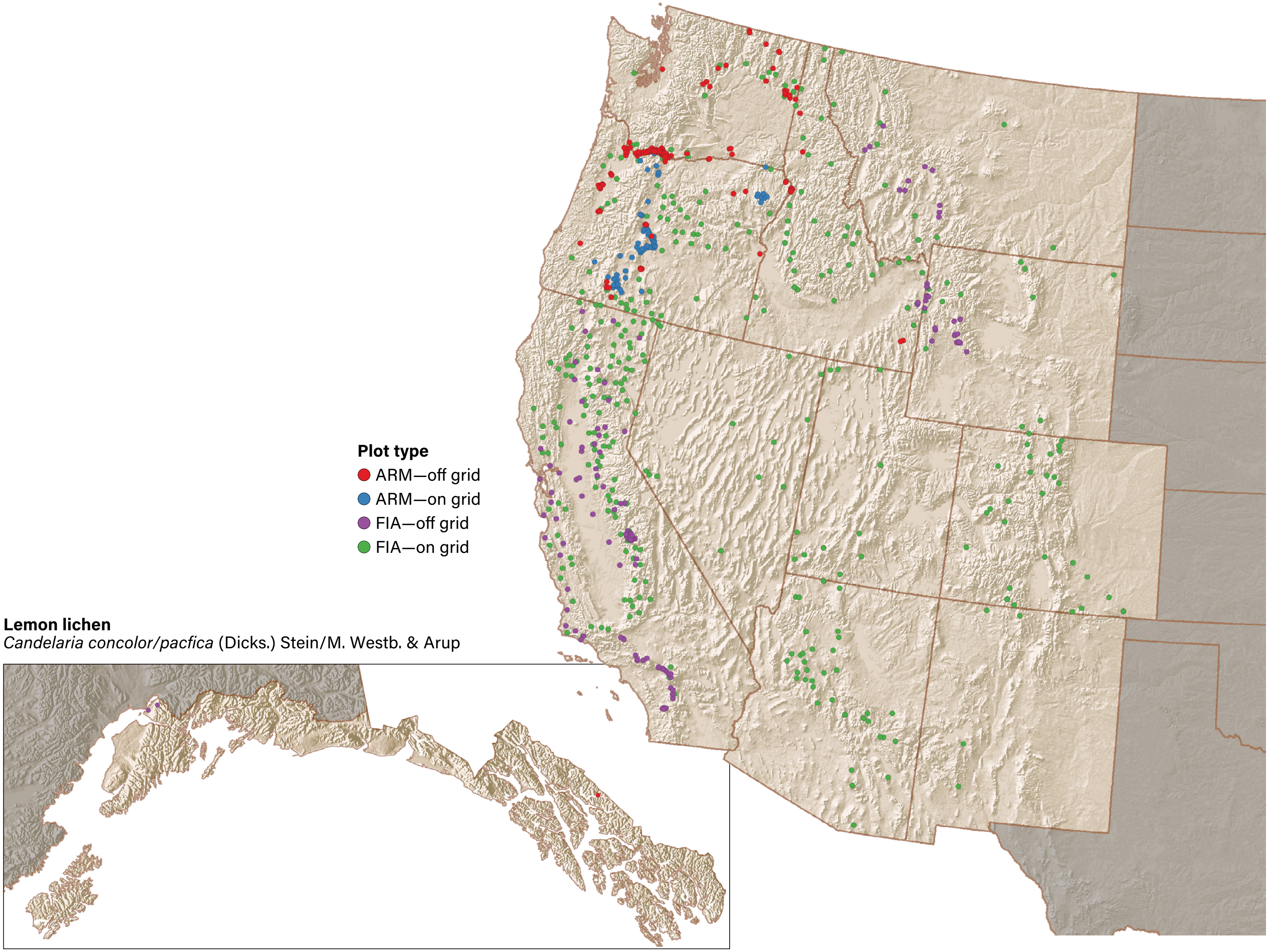
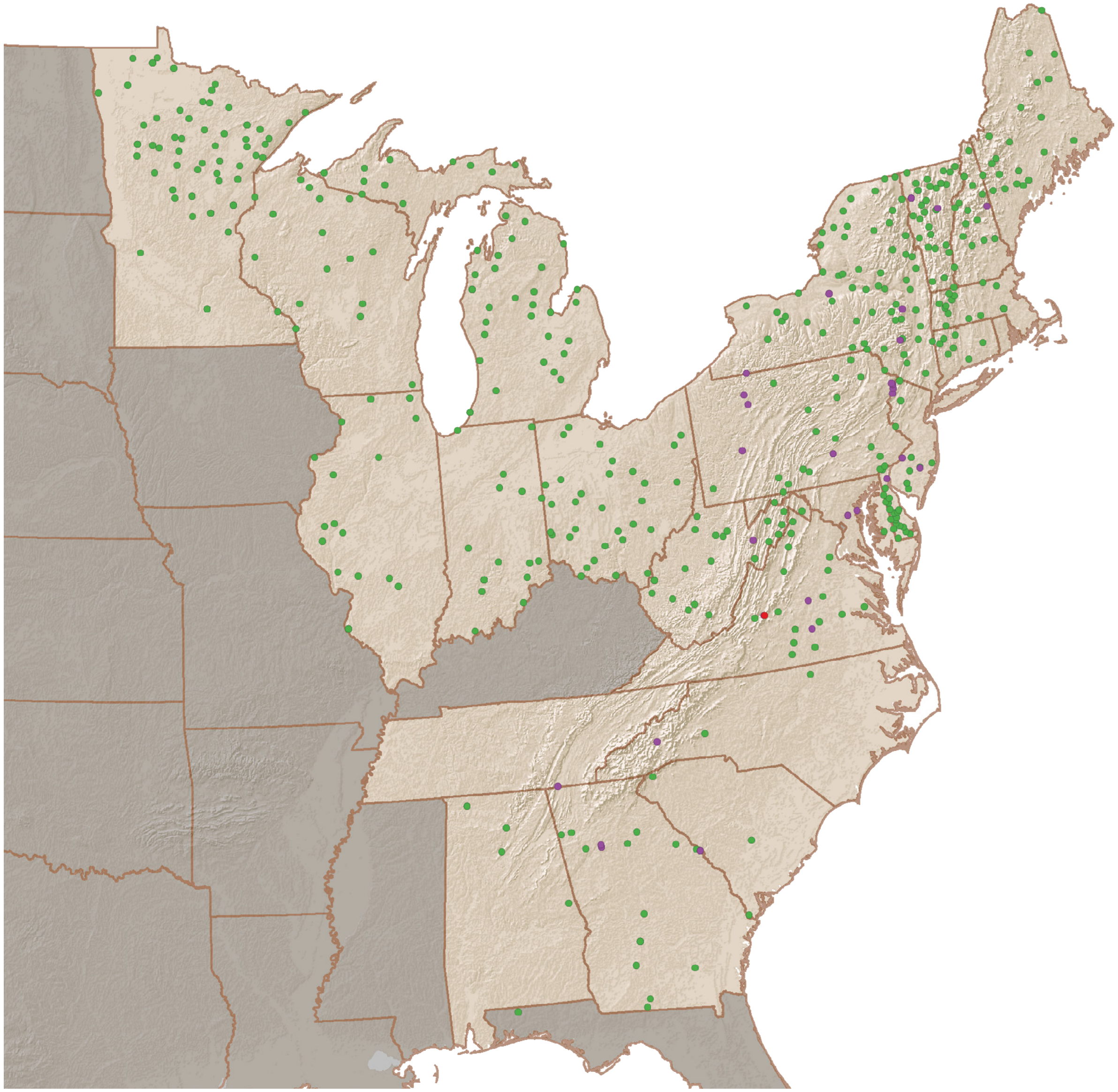


Figure 7.3—Map of Indicator surveys where Candelaria concolor *and* C. pacifica *were found on Air Resource Management (ARM) and Forest Inventory and Analysis (FIA) plots. These species are mapped together because their sterile forms are difficult to differentiate. Western records are likely* C. pacifica, *while eastern records are likely* C. concolor. *Plot locations are approximate.*



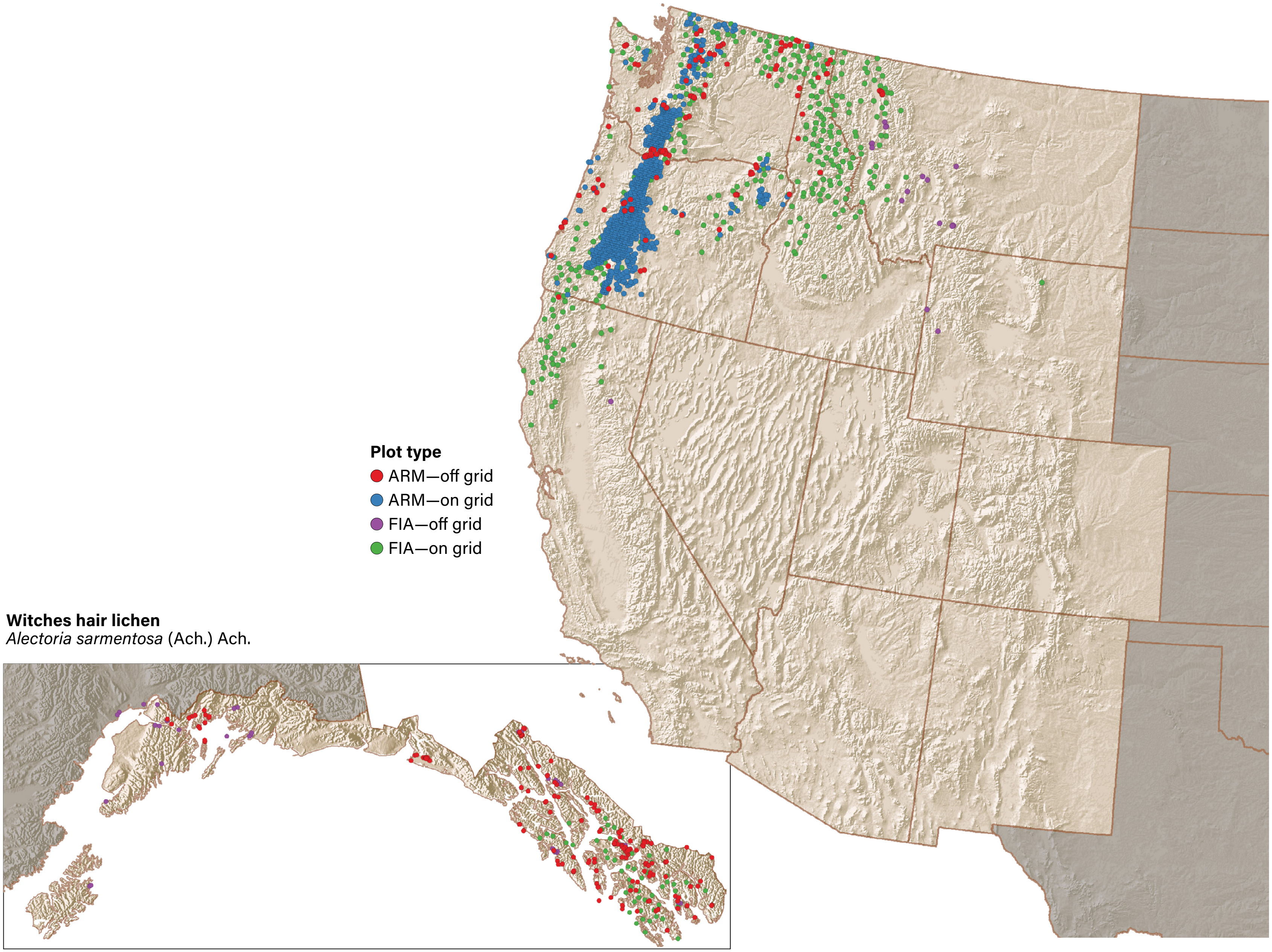


Figure 7.4—Map of Indicator surveys where Alectoria sarmentosa *was found on Air Resources Management (ARM) and Forest Inventory and Analysis (FIA) plots. Plot locations are approximate.*

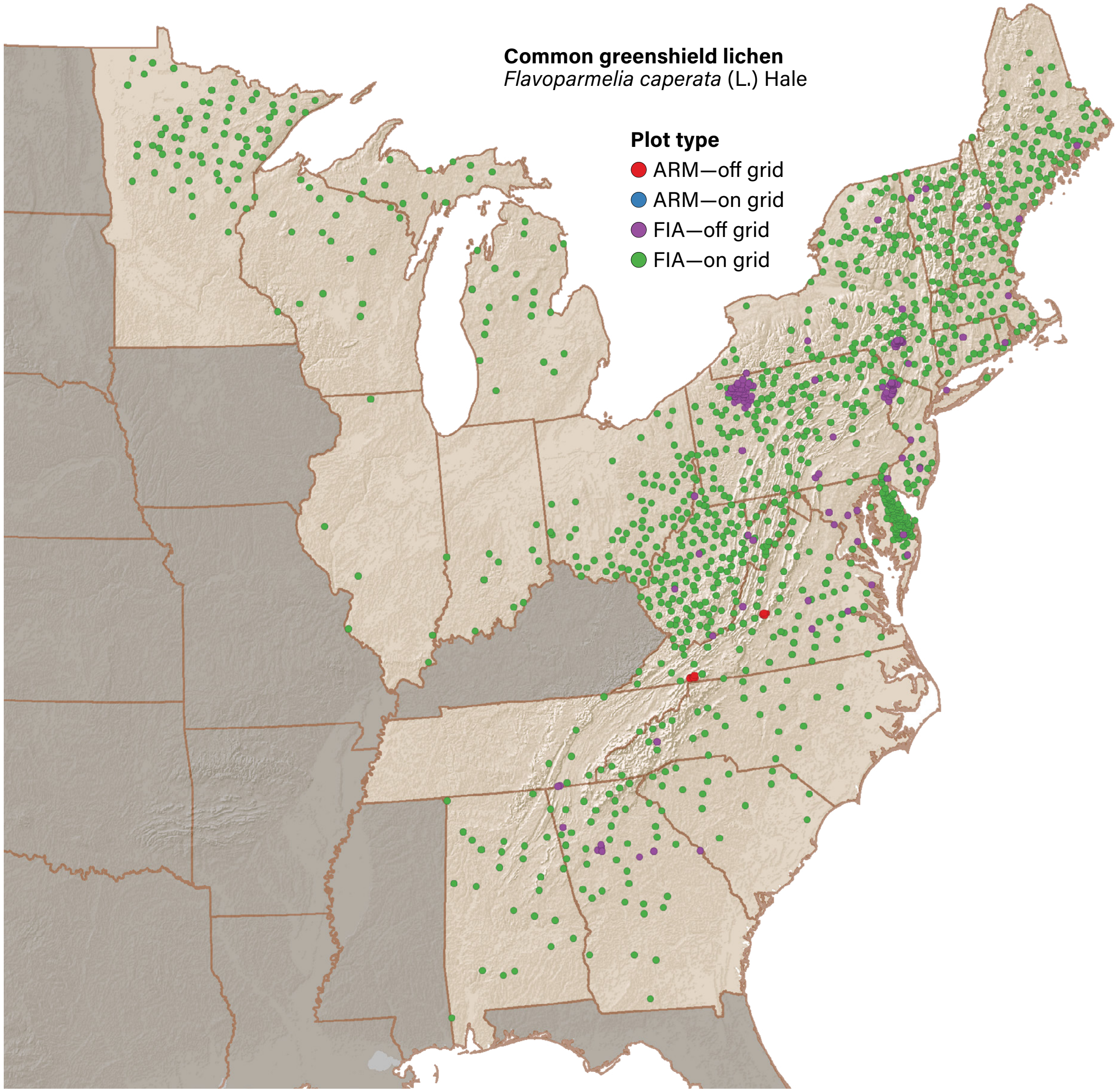


Figure 7.5—Map of Indicator surveys where Flavoparmelia caperata *was found on Air Resources Management (ARM) and Forest Inventory and Analysis (FIA) plots. Plot locations are approximate.*

CONCLUSIONS

Publication of the NFLD version 1.0 and National Lichen Atlas marks a significant milestone, making data from thousands of lichen surveys conducted from 1989 to 2012 available to the public for the first time. Despite reduced data collection since 2012, the ARM and FIA programs have maintained their long-term partnership to continue serving clients of the Indicator, making data more readily available and, when possible, supporting additional data collection to answer specific research or management questions. Future versions of the NFLD will incorporate these newer datasets, including assay data where available.

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