Invasive Plant Atlas of New England: The Role of Citizens in the Science of Invasive Alien Species Detection

SARAH T. BOIS, JOHN A. SILANDER JR., AND LESLIE J. MEHRHOFF

In response to the global threat of invasive alien species, there has been a proliferation of volunteer-based monitoring programs. The valuable data sets collected through these programs facilitate large-scale, baseline population monitoring. The Invasive Plant Atlas of New England, created in 2001, was the first such regional database and is the only one in which both presence and true absence data have been collected. Building on the success of volunteer atlas projects for other taxa, the Web-based network uses trained volunteers, along with experts, to collect distribution data and detailed environmental information. The incorporation of true absence data allows for the building of robust statistical models, which contributes significantly to the invasive species literature. This collaborative database allows citizen science data to be used by the general public and as a data source for researchers and policymakers. As a template for other invasive plant projects, we highlight the need for more collaborative efforts in invasion ecology.

Keywords: citizen science, species distribution database, invasive species, IPANE, null data

Survey and monitoring programs have developed across the globe in response to the common issues of invasive species and biodiversity conservation. Crall and colleagues (2006) found at least 319 databases that contained invasive species distributional information in the United States, and that number has been steadily growing. Distributional data for invasive alien species (IAS) are being collected at multiple spatial scales, from property-specific, local monitoring programs to the Global Invasive Species Information Network (*www.gisinetwork.org*). In these programs, data are assembled under disparate collection protocols and are often limited to only species-presence information, and many databases are not available online (Crall et al. 2006). Although these data are useful for establishing baseline distribution information, the lack of true absence data (location information for areas surveyed but free of invaders) limits the ability to accurately predict potential species distributions in a statistical context and to assess the uncertainty in those predictions (Gelfand et al. 2005, 2006, Barry and Elith 2006). This is especially true of IAS new to a region.

The Invasive Plant Atlas of New England

The Invasive Plant Atlas of New England (IPANE) was the first atlas project that we know of dedicated to documenting invasive species. Created in 2001, IPANE was founded in order to coordinate the efforts of the six New England states of the northeastern United States. At the time, an estimated 30%–35% of the plant species in New England were considered alien to the region, with 3%–5% of the aliens deemed aggressive invaders (Mehrhoff 2000). Designed to resemble atlas projects on other taxa, IPANE's initial goals were to evaluate the status and spread of IAS, to increase public awareness, to establish methodologies of data collection and dissemination, and to develop early-detection capabilities (Mehrhoff et al. 2003). This distributional database and information network has become a transboundary survey and monitoring program across the six New England states of the United States (Massachusetts, Connecticut, Rhode Island, Vermont, New Hampshire, and Maine), standardizing data collection and assessment methods while functioning as a nexus for information sharing among project staff, volunteers, stakeholders, landowners, and the public at large.

Citizens as volunteer scientists

The use of nonspecialists to collect data is not an idea new to science. Amateur and hobby naturalists have been observing and collecting specimens for centuries. These early collections covered all corners of the Earth and were assembled for curiosity, for novelty, and for medicinal, artistic, and scientific purposes. Amateur naturalists and botanists were among the primary groups responsible for the detection of many new species and for publishing distributional notes, thus making these observations public (Keeney 1992).

BioScience 61: 763–770. ISSN 0006-3568, electronic ISSN 1525-3244. doi:10.1525/bio.2011.61.10.6

At the height of the naturalist collections in the nineteenth century, experienced amateurs and professionals exchanged data, specimens, and ideas (Keeney 1992). It was recognized that more information could be gathered from compiled collections than from the efforts of an individual. Networks of societies, journals, and institutions allowed for an information flow at the local, regional, and national level among professionals and amateurs. The collective knowledge of amateurs and professionals allowed John Torrey and Asa Gray to compile the *Flora of North America* around 1838, which was the first comprehensive attempt to describe the flora of the continent (Short 2004). It was not until the late 1890s, when professionals began to outnumber amateurs and to turn more toward scientific research, that professional-only societies emerged (Keeney 1992).

The use of volunteers has reemerged as a primary method for large-scale data collection, primarily because of the advances in technology and data analysis techniques (Silvertown 2009). The advent of the Internet and the proliferation and availability of home computers allows for the easy exchange of ideas, images, and files, and enables people from different corners of the globe to converse and to view and discuss the same images in real time. Efforts to disseminate information that would previously have taken years take only seconds today. This new era of volunteer data collection has been a boon to atlas projects and monitoring programs alike. Atlas project staff and managers can organize volunteers, disseminate information, and collect information from multiple sources quickly and easily (Silvertown 2009).

Large-scale survey and monitoring efforts such as IPANE require sufficient numbers of knowledgeable data collectors in order to achieve species documentation goals. The global decrease in professional taxonomists over the last 50 years has led to an increased reliance on amateur scientists for species identification and data collection (Hopkins and Freckleton 2002, Prather et al. 2004). The current inadequacy in the number of professional naturalists and taxonomists has meant fewer observations of new species (Crawford and Hoagland 2009). The sheer breadth of data required for large-scale distribution modeling is beyond the economic and geographic feasibility of most atlas projects, were they to hire experts to complete surveys. Many atlas projects, including IPANE, have overcome this deficiency by training volunteers to collect field data and reserving experts for verification of questionable identifications, data quality checking, and assessments of new and important incursions. Since volunteers are themselves geographically dispersed, they often produce better overall spatial coverage than point efforts of experts or employees who must travel to the survey destinations (Hopkins and Freckleton 2002). The use of trained volunteers provides a cost-effective way to implement large-scale data collection and enhances the efforts of botanical professionals (Hopkins and Freckleton 2002, Levrel et al. 2010). In France, for example, it has been estimated that volunteer-based surveys for bird and butterfly abundances and distributions has saved the government (i.e., the taxpayers) between €678,523 and €4,415,251, depending on the pay scale of the professionals and the skill level of the volunteers (Levrel et al. 2010). These data are then used to determine conservation goals and public policy. The use of volunteers also provides the opportunity to engage the public in the scientific method. This participation in the scientific method has the potential to change the public's perception of scientists and scientific issues and may help recruit people into the sciences (Cooper et al. 2008, Silvertown 2009). When volunteers are educated about scientific data collection and the value of scientific inquiry, they truly become citizen scientists.

Today, the use of volunteers and amateurs to collect scientific data is perhaps best recognized in the field of ornithology. The Christmas Bird Count (CBC) and the North American Breeding Bird Survey (BBS) have been collecting species distribution data since 1900 and 1965, respectively (Bock and Root 1981, Ziolkowski 2008). These early atlas projects brought the efforts of many individuals under a standard set of protocols. The longevity of the data collected under a single methodology makes them particularly valuable for observing long-term changes in distributions and abundances.

The CBC and the BBS have created some of the most extensive avian population data available today and have generated important baseline population information (Sauer et al. 2003). The large-scale surveys help highlight holes in the current survey work or areas in need of more intensive study (e.g., Butcher and Schwarz 1987). Because of its systematic methodology, BBS data has been used extensively in the predictive statistical modeling of species distribution changes and in the spread of invasive avian fauna (e.g., Wickle 2003, Hooten and Wickle 2008).

The Xerces Society, started in 1975, modeled its 4th of July butterfly count after the CBC, which has resulted in an extensive data set invaluable to lepidopteron conservation (Swengel 1990). For both the CBC and the Xerces Society count, the varying identification abilities of volunteers, the desire of some volunteers to canvass particular areas instead of others, and the favoring of rare and charismatic species potentially bias their results and can influence data quality (Swengel 1990). New volunteers with the BBS have been known to count more birds than volunteers who have been with the program longer, potentially because they overestimate the numbers of particular species (Sauer et al. 1994). Although there may be some issues with the evenness of its data collection, the value of this data set lies in the large geographic range of the data and in its temporal scale and open availability to the public. Current analysis tools also allow us to deal with uncertainty in the data generated by volunteer collection. Specifically, Bayesian models, which are being used more often to incorporate data from multiple data sources, are able to incorporate the uncertainty that occurs with underreporting (Powers et al. 2010), measurement or classification error (Chakraborty et al. 2010), location error (Barber et al. 2006), or incomplete survey information (Wilson et al. 2008).

Building on previous projects, IPANE limits sampling bias and discrepancies in identification ability through the training of the volunteer pool. By training all volunteers to identify the same list of species, we can assure that the ability to detect a particular plant is more or less equal among the volunteers. IPANE used the CBC, the BBS, and the Protea Atlas Project (*http://protea.worldonline.co.za/default.htm*) as models for project and survey design. IPANE established a systematic method of surveying invasive occurrences in the region that could be implemented by trained volunteers and used as a model for invasive atlas projects in other regions.

Training

IPANE actively recruits, trains, and coordinates volunteers in IAS identification and the collection of scientific, replicable data. Multiple training programs are offered each year for new volunteers and to refresh the current volunteer pool. In addition to species identification, volunteer training is focused on the necessity of spatial completeness in data collection, of consistency of methodology, and of collecting null data. Without absence data, the probabilities of species being present at particular locations or across regions generally cannot be estimated with true statistical certainty (but see Chakraborty et al. 2011 and Warton and Shepherd 2010). The collection of valid absence data allows the building of robust statistical models using IPANE distributional and associated environmental data (Gelfand et al. 2005, 2006, Silander et al. 2007, Ibáñez et al. 2009a, 2009b). All volunteers must be trained prior to their being able to enter data into the database: In this way, data quality is ensured.

Data collection

The volunteers are instructed to collect data from multiple habitat types within publicly accessible natural or seminatural areas. By assigning these survey areas, we assure that the volunteers' efforts are distributed spatially, and the likelihood of species detection is increased throughout the region. For each habitat type within the survey region, a 20-meter-diameter circular sampling plot is established. Location data are recorded as GPS (global positioning system) coordinates or as points on a map. Habitat type and plot-level site conditions are assessed. These data are collected in ordinal categories (e.g., soil moisture categories from 1 to 4 in order of increasing moisture content) for ease of assessment and synchronicity with other volunteers. Inside the plot, each IAS is identified, and data are taken on the abundance, distribution, percentage of the area that the species covers, and the reproductive stage for each species. Some species require documentation, such as specimens or photos of specific identifying characteristics of the plant or habitat, to be later verified by IPANE staff. This is the next step in data quality assurance. Once the data are collected, IPANE volunteers enter their own data online (at *www.ipane.org*), which are then available to the public through the IPANE Web site.

Absence data are collected by the IPANE volunteers in two ways. Null plots, where there are no invasive species present, are collected in uninvaded habitat types within assigned natural areas. The same habitat descriptions and explanatory data are collected that were assessed for the plots with IAS. These plots are important for noting habitats and locations where nonnative species are absent. In addition, a species is considered absent in the plots when another IAS is present but the particular species of interest has not been found in the plot. Unlike detection issues that arise with animal surveys (e.g., Royle et al. 2007), we can assume, at least for the more common and easily identifiable IAS that the volunteers are trained to identify, that the adult or juvenile form of the plant is very likely absent from a surveyed location if it has not been detected by our trained volunteers.

Data vetting

The current use of nonspecialist volunteers for data collection has sometimes been questioned for its accuracy and reliability. Studies validating this type of data collection have been conducted for a diverse group of taxa, including terrestrial invertebrates (Lovell et al. 2009), invasive crab identification and sex determination (Delaney et al. 2008), oak stand surveys (Galloway et al. 2006), and invasive plant identification and abundance estimates (Brooks et al. 2008). These studies and others like them have shown that, with some amount of focused training, the identification abilities of volunteers, from school-age children to senior adults, are at an acceptable level of accuracy when compared with the results of "experts" or paid professionals. A study on the use of citizen scientists in collecting invasive plant distribution data in New York and New Jersey forestland showed that trained volunteers were often more accurate than paid employees in the assessments of percentage of the area covered by the species and canopy closure when their data were verified by an "expert" (Brooks et al. 2008). These validations, along with the countless studies in the literature in which volunteer-collected data were relied on, support the value of citizen science as a powerful ecological tool.

IPANE has a two-step verification process. First, volunteers are trained in identification and data collection methods, as was previously stated. Second, certain species reports may require confirmation from the project staff prior to posting. These species are those that are particularly difficult to identify, are easily confused with another species (e.g., *Ligustrum* or *Lonicera* species), or are new to a region. Further help in identification is available on the IPANE Web site, including photos, botanical descriptions, and identification keys. Once they are confirmed, the data are available to the public through the IPANE Web site.

Data produced

Citizen science and atlas projects have proliferated in the last decade. A search on the Web of Science yielded 611 records that include the term *citizen science* in the topic (completed

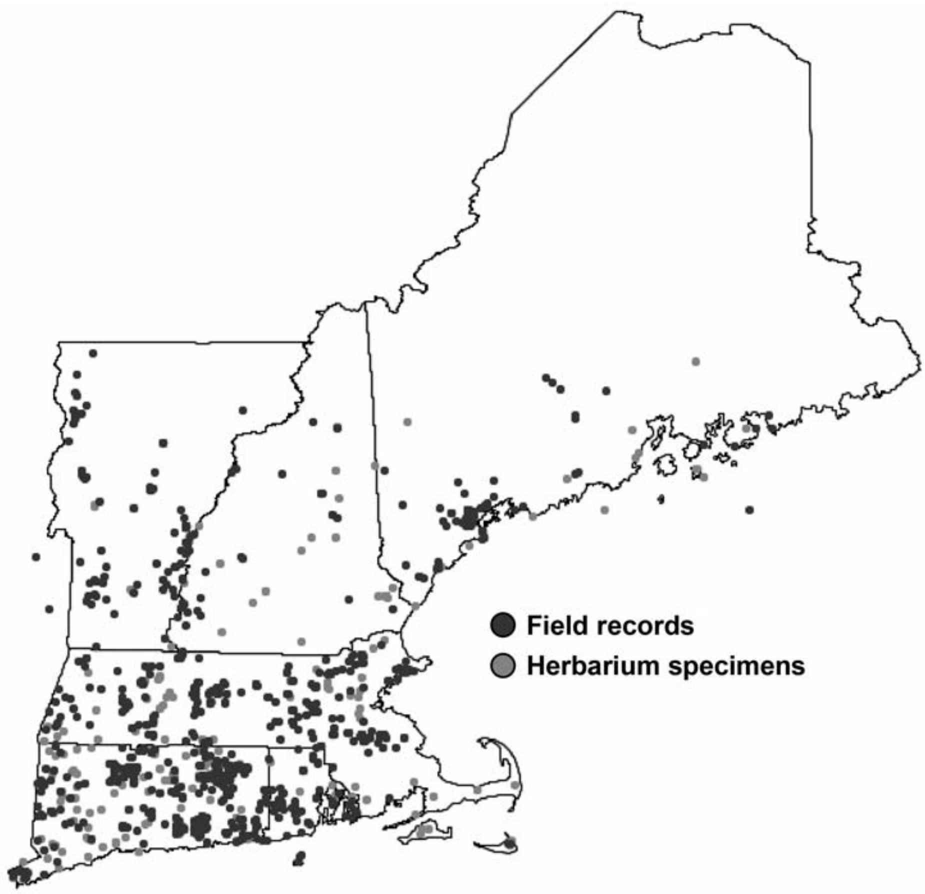

*Figure 1. Invasive Plant Atlas of New England data application. Data can be downloaded from the Web site (*www.ipane.org*) in table and map (above) form for* **Berberis thunbergii** *(Mehrhoff et al. 2003). There are 1104 IPANE field records (dark gray) for* **B. thunbergii** *and 233 herbarium records (light gray).*

on 19 January 2011). Of those, about 79% were published since 2000, and 25% were from 2009 and 2010. This increasingly popular topic will remain an important ecological and biogeographical tool for scientists.

As the first regional atlas project of its kind, IPANE has trained over 900 volunteers to date. This survey force has submitted more than 5500 field forms documenting the location of some 12,200 individual IAS occurrences across the six New England states. This large data set makes IPANE particularly useful for investigating patterns of IAS distributions and invasion fronts throughout the region. It also allows IPANE staff to identify undersurveyed areas in New England, in which survey efforts may need to be targeted. The IPANE database also houses over 8000 individual herbarium records from more than 20 regional herbaria. These records represent both historical and current species-presence information and are kept separate from IPANE-collected data because they were collected using disparate methods with varying amounts of associated data. These data have been used to independently validate the predictive models of IAS on the basis of field-collected data (Ibáñez et al. 2009a, 2009b).

Data use and publications

After data are posted to the IPANE Web site, the public has open access to download the field-collected occurrence data in table, map, or comma-delimited form, along with the herbarium records available in the database (figure 1). It is important for atlas projects such as IPANE to maintain the online database as an educational resource for volunteers and the general public (Simpson et al. 2006). In accordance with its mission statement, IPANE provides individual species information, resource and management links, native alternatives to horticultural invasives, removal events, related meetings and conference information, and the distribution data and maps (*www.ipane.org*). This comprehensive Web-based tool provides an information hub for the public and volunteers facilitating the collection and for the analysis and communication of information related to invasive species management in New England. Training events and the IPANE LISTSERV are tools used to educate volunteers, to disseminate the results of scientific study, and to alert the volunteers to potential incursions of new species in their region. As a social network, the IPANE LISTSERV allows the volunteers to submit postings on related issues and encourages discussion among its members. It is important that this interactive feedback nature of IPANE be preserved: The volunteers collect data, which are used for research, and the research is distributed to the volunteers through training sessions and the Web site. Providing the public with access to this interactive resource promotes information exchange and open communication among similarly interested parties. The IPANE data and Web site are also used by conservation land managers, from public agencies and nonprofit agencies alike, to aid in setting priorities for invasive species control and management. Information on individual occurrences, abundances, reproductive status, and associated species all assist those working with IAS as they plan for future management strategies (Mehrhoff et al. 2003).

The scientific output of atlas projects such as IPANE reflects the culmination of the efforts of many individuals. Long-term data sets, such as the CBC and the annual Xerces Society Lepidoptera count, have proven invaluable to species conservation (Swengel 1990). These spatially and temporally expansive data sets are used for educational purposes, to drive legislation, and to develop and validate predictive models. For longer-term atlas projects such as the CBC and BBS, data can be examined over time to resolve temporal–spatial patterns of change (Wickle 2003, Butcher and Niven 2007, Hooten and Wickle 2008) and to allow scientists, landscape managers, and policymakers to identify threats to and conservation priorities for species of interest.

One example of the use of IPANE data is the incorporation of the volunteer-collected data into predictive species distribution models. These models allow researchers to investigate the potential spread of IAS and to identify likely areas of new incursions. Distributional patterns are difficult to predict when a species is new to an area, but they have important management implications in the case of IAS, in which a species may not have realized its potential range (Welk 2004). The available distributional data are often incomplete or nonexistent and lack true absence data, which severely limits the ability to model potential distributions (Welk 2004, Barry and Elith 2006, Myerson and Mooney 2007). The use of herbarium data alone is biased by collection effort and can result in the recording of false absences (Crawford and Hoagland 2009). IPANE data that consists of both presence and absence data are useful for distinguishing true absences from undersurveyed areas. For example, *Berberis thunbergii* populations have been extensively searched for in southern New England and also along the coast of Maine (figure 2). The inferred absence data in this region reflect sites at which the species is truly missing. This contrasts with the locations in central New Hampshire and northern Maine, which have been only sparsely surveyed. These are two very different types of absence data. The use of IPANE field-collected data for predictive modeling is of particular importance in identifying IAS hot spots and in forecasting future incursions or distributional changes due to environmental influences such as global climate change (cf. Ibáñez et al. 2009a, 2009b, Merow et al. 2011).

For example, in collaboration with colleagues in Japan, we have combined IPANE data with East Asian distributional data sets to build predictive distribution models for IAS in New England (Silander et al. 2007, Ibáñez et al. 2009a, 2009b). Although it is not the purpose of this article to focus on the details of distribution modeling that are presented in detail by authors elsewhere, using the methods of Ibáñez and colleagues (2009a), we show that the model that provides the best predictions incorporates native-range data from Japan and invasive-range data from New England (figure 3), as well as land-use and habitat data. Models tested using solely Japan or New England data did not predict the New England distribution as well as the model incorporating both locations did (Ibáñez et al. 2009a, 2009b). These results highlight the necessity for global collaboration among databases.

The predicted potential distributions for *B. thunbergii* in New England (figure 3) indicate a high probability of the species' eventually spreading to northern Maine, which is outside its known range. This research highlights potential areas on which to focus early-detection efforts of our volunteer network. This same pattern is shown for *Celastrus orbiculatus*, *Elaeagnus umbellata*, and *Rosa multiflora* (figure 3). There is a generally high uncertainty in the predicted probability of *B. thunbergii* presence in northern New England (Ibáñez et al. 2009a)

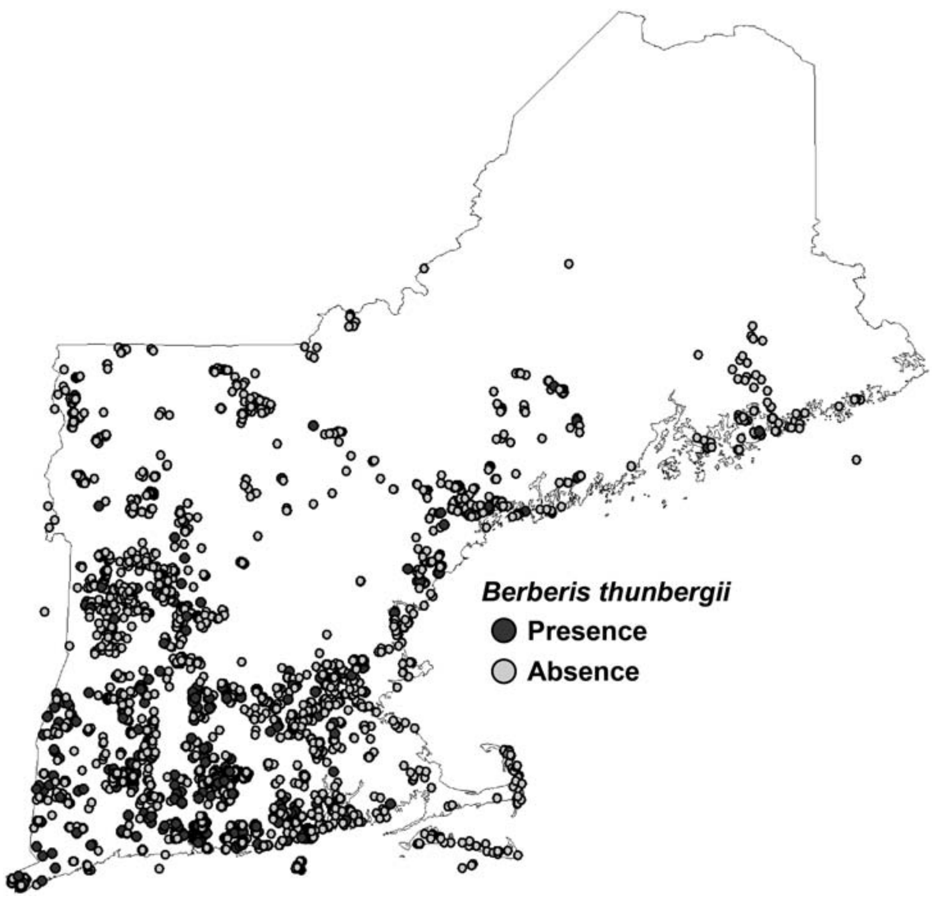

Figure 2. Presence (dark gray) and absence (light gray) data for* Berberis thunbergii *in New England. These data are from Invasive Plant Atlas of New England (IPANE) data plots (Mehrhoff et al. 2003) and were used by Ibáñez and colleagues (2009a, 2009b).

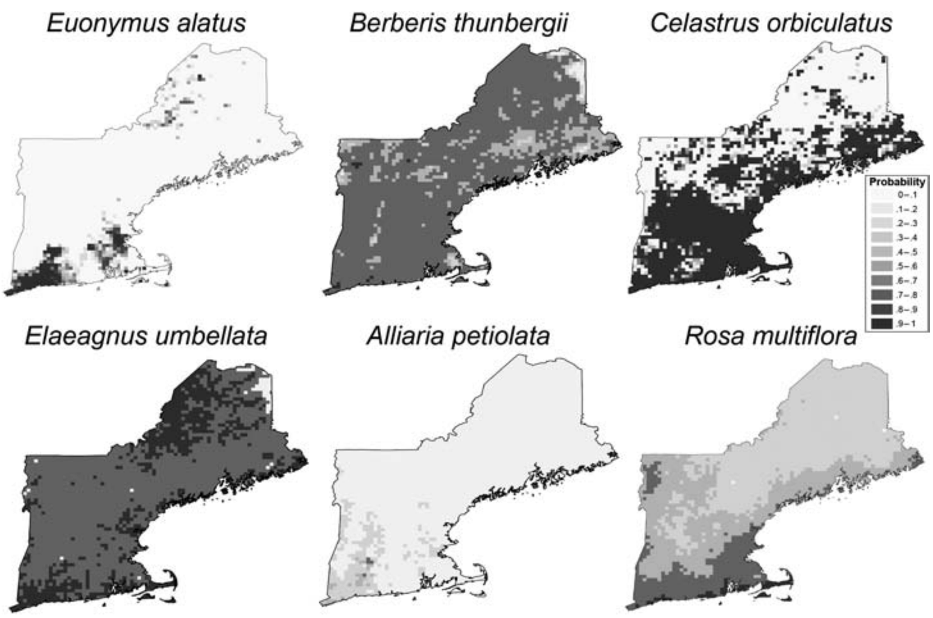

Figure 3. The potential distributional range of six common New England invasive species. These results were generated from a hierarchical Bayesian model that incorporates climate data from New England and Japan, New England site characteristics (habitat type and canopy closure), and New England land use and land cover (adapted from Silander et al. 2007, Ibáñez et al. 2009a). The darker shades indicate areas of high probability of establishment, given the presence of propagules.

relative to those of southern and central New England. This may reflect, in part, the fact that northern New England is undersampled (figure 2). Volunteer recruitment and training opportunities are now focused in these more sparsely settled areas to obtain better overall survey coverage in the region. Once new information has been collected, the predictive distribution models can be updated and new maps created, thus continuing the cyclic nature of IPANE.

The open-source availability of IPANE species information and presence or absence and abundance data have led to its contribution to a variety of published studies at the regional and national scales. IPANE distributional data can be categorized by its various uses: ecological–biological purposes (see supplementary table S1a online at *http://dx.doi.org/10.1525/bio.2011.61.10.6*) and single-species applications (table S1b). In a survey of IPANE users, we found that the primary daily uses of the Web site are for species identification and educational purposes. Other noncited uses included the use of IPANE photographs, the gathering of management information, and use by state agencies. IPANE has also been used as a template for other atlas projects, including the Invasive Plant Atlas of the MidSouth (IPAMS). The IPAMS (*www.gri.msstate.edu/research/ipams/about.php*) monitoring protocol was directly modeled after IPANE's, whereas other aspects were tailored to the specific needs of that region.

We are currently working on new partnerships that will allow for data exchange among IPANE and other atlas projects. This new collaboration will allow IPANE data to be viewed alongside national and international data sets through the EDDMapS project (*www.eddmaps.org*). Efforts to combine such data need to include metadata explaining the differences among the various data sets. These differences include the data collection methods, uncertainty in location information, and identification issues. As long as the data are transparent, the users of the data can make an informed decision about which data to use.

Conclusions

It has been only in the last 20 years that technological and analytical advances have made species distribution data collection and management feasible at such a large scale. The vast amount of data necessary for large-scale distributional studies can be possible only with the use of a trained volunteer corps. IPANE has built on the success of other volunteer-sustained databases by gathering like-minded individuals from professional botanists, master gardeners, and botany enthusiasts to schoolteachers, their students, and interested homeowners. The inclusion of true absence data and of the fail-safes established for data vetting has allowed IPANE to be an example of citizen science data collection, organization, and use and of the ways in which the volunteer corps contributes to the science of invasion ecology.

As new databases and mapping systems become available, we need to find ways to work together to make data sharing possible and easy. Instead of reinventing the wheel and creating new databases and atlas projects, we should invest in continuity and sustaining existing long-term projects. Not only will this improve the temporal scale of the data but it will give volunteers confidence to be loyal to established data collection protocols.

The use of volunteer-collected distributional data has been increasingly recognized for its value to the scientific community. The public is engaged in actually doing science and understanding the nature of scientific inquiry. Together, volunteers can provide wider-reaching information from more areas congruently than can expert scientists alone. As is evidenced by the history of volunteer-collected data in avian fauna, the value of such coordinated studies lies in the sheer volume of data points available for analysis. Atlas projects like IPANE train the volunteer corps to identify species but also in systematic field collection methods. They are a valuable force of early-detection observers across the landscape. These volunteer scientists are not only data collectors and citizen scientists but ambassadors for IAS education and biodiversity conservation.

Acknowledgments

We acknowledge the US Department of Agriculture for funding support (USDA-NRI Grants #2001-52103-1130, #2005-02217, and #2008-03237), and we also received support from the US Geological Survey. We acknowledge the considerable efforts of all those involved in the initiation of the IPANE program: Bill Brumback, Chris Mattrick, Bryan Connolly, Ted Elliman, Cynthia Boettner, and Beth Goettel. Stacey Leicht-Young, Nava Tabak, and Nancy LaFleur worked closely with volunteers. Many early discussions about working with volunteers were with Randy Westbrooks. Thanks to Annie Simpson, Marcia McNiff, and the National Biological Information Infrastructure for supporting the volunteer network. Kent Holsinger and three anonymous reviewers provided useful comments.

References cited

Barber JJ, Gelfand AE, Silander JA Jr. 2006. Modelling map positional error to infer true feature location. Canadian Journal of Statistics 34: 659–676.

Barry S, Elith J. 2006. Error and uncertainty in habitat models. Journal of Applied Ecology 43: 413–423.

Bock CE, Root TL. 1981. The Christmas Bird Count and avian ecology. Studies in Avian Biology 6: 17–23.

Brooks WR, Mellor DT, Ehrenfeld JG, McGowan E, Goodell E, Jordan R. 2008. Using Citizen Scientists to Collect Plant Distribution Data in NY/NJ Forest Land. Paper presented at the Northeast Natural History Conference, 17–18 April, Albany, NY.

Butcher GS, Niven DK. 2007. Combining Data from the Christmas Bird Count and the Breeding Bird Survey to Determine the Continental Status and Trends of North America Birds. National Audubon Society. (20 July 2011; *http://stateofthebirds.audubon.org/cbid/content/Report.pdf)*

Butcher G[S], Schwarz P. 1987. Database management in bird population studies. Birdscope 1: 9.

Chakraborty A, Gelfand AE, Wilson AM, Latimer AM, Silander JA Jr. 2010. Modeling large scale species abundance with latent spatial processes. Annals of Applied Statistics 4: 1403–1429.

———. 2011. Point pattern modeling for degraded presence-only data over large regions. Journal of the Royal Statistical Society. Forthcoming.

Cooper CB, Dickinson JL, Phillips T, Bonney R. 2008. Science explicitly for nonscientists. Ecology and Society 13, 2, Resp. 1. (18 July 2011; *www.ecologyandsociety.org/vol13/iss2/resp1*)

Crall AW, Meyerson LA, Stohlgren TJ, Jarnevich CS, Newman GJ, Graham J. 2006. Show me the numbers: What data currently exist for non-native species in the USA? Frontiers in Ecology and the Environment 4: 414–418.

Crawford PHC, Hoagland BW. 2009. Can herbarium records be used to map alien species invasion and native species expansion over the past 100 years? Journal of Biogeography 36: 651–661.

Delaney DG, Sperling CD, Adams CS, Leung B. 2008. Marine invasive species: Validation of citizen science and implications for national monitoring networks. Biological Invasions 10: 117–128.

Galloway AWE, Tudor MT, Haegen WMV. 2006. The reliability of citizen science: A case study of Oregon White Oak stand surveys. Wildlife Society Bulletin: 34: 1425–1429.

Gelfand AE, Schmidt AM, Wu R, Silander JA Jr, Latimer A, Rebelo AG. 2005. Modeling species diversity through species level hierarchical modeling. Journal of the Royal Statistical Society 54C: 1–20.

Gelfand AE, Silander JA Jr, Wu S, Latimer A, Lewis PO, Rebelo AG, Holder M. 2006. Explaining species distribution patterns through hierarchical modeling. Bayesian Analysis 1: 42–92.

Hooten MB, Wickle CK. 2008. A hierarchical Bayesian nonlinear spatio-temporal model for the spread of invasive species with application to the Eurasian collared-dove. Environmental and Ecological Statistics 15: 59–70.

Hopkins GW, Freckleton RP. 2002. Declines in the numbers of amateur and professional taxonomists: Implications for conservation. Animal Conservation 5: 245–249.

Ibáñez I, Silander JA Jr, Wilson A, LaFleur N, Tanaka N, Tsuyama I. 2009a. Multi-variate forecasts of potential distribution of invasive plant species. Ecological Applications 19: 359–375.

Ibáñez I, Silander JA Jr, Allen JM, Treanor SA, Wilson A. 2009b. Identifying hotspots for plant invasions and forecasting focal points of further spread. Journal of Applied Ecology 46: 1219–1228.

Keeney EB. 1992. The Botanizers. University of North Carolina Press.

Levrel H, Fontaine B, Henry P-Y, Jiguet F, Julliard R, Kerbiriou C, Couvet D. 2010. Balancing state and volunteer investment in biodiversity monitoring for the implementation of CBD indicators: A French example. Ecological Economics 69: 1580–1586.

Lovell S, Hamer M, Slotow R, Herbert D. 2009. An assessment of the use of volunteers for terrestrial invertebrate biodiversity surveys. Biodiversity and Conservation 18: 3295–3307.

Mehrhoff LJ. 2000. Immigration and expansion of the New England flora. Rhodora 102: 280–298.

Mehrhoff LJ, Silander JA Jr, Leicht SA, Mosher ES, Tabak NM. 2003. IPANE: Invasive Plant Atlas of New England. University of Connecticut, Storrs. (18 July 2011; *http://nbii-nin.ciesin.columbia.edu/ipane*).

Merow C, LaFleur N, Silander JA Jr, Wilson A, Rubega M. 2011. Developing dynamic, mechanistic species distribution models: Predicting bird-mediated spread of invasive plants across northeastern North America. American Naturalist 178: 30–43.

Meyerson, LA, Mooney HA. 2007. Invasive alien species in an era of globalization. Frontiers in Ecology and the Environment 5: 199–208.

Powers S, Gerlach R, Stamey JD. 2010. Bayesian variable selection for Poisson regression with underreported responses. Computational Statistics and Data Analysis 54: 3289–3299.

Prather LA, Alvarez-Fuentes O, Mayfield MH, Ferguson CJ. 2004. Implications of the decline in plant collecting for systematic and floristic research. Systematic Botany 29: 216–220.

Royle JA, Kéry M. 2007. A Bayesian state-space formulation of dynamic occupancy models. Ecology 88: 1813–1823.

Sauer JR, Peterjohn BG, Link WA. 1994. Observer differences in the North American Breeding Bird Survey. Auk 111: 50–62.

Sauer JR, Fallon JE, Johnson R. 2003. Use of North American breeding bird survey data to estimate population change for bird conservation regions. Journal of Wildlife Management 67: 372–389.

Short PS. 2004. In Pursuit of Plants: Experiences of Nineteenth and Early Twentieth Century Plant Collectors. Timber Press.

Silander JA Jr, Ibáñez I, Mehrhoff LJ. 2007. The biology and ecology of invasive species—The importance of international collaboration in predicting the spread of invasive species. Paper presented at the NIAES International Symposium, Tsukuba, Japan, 22–23 October.

Silvertown J. 2009. A new dawn for citizen science. Trends in Ecology and Evolution 24: 467–471.

Simpson A, Sellers E, Grosse A, Xie Y. 2006. Essential elements of online information networks on invasive alien species. Biological Invasions 8: 1579–1587.

Swengel AB. 1990. Monitoring butterfly populations using the Fourth of July butterfly count. American Midland Naturalist 124: 395–406.

Warton DI, Shepherd LC. 2010. Poisson point process models solve the "pseudo-absence problem" for presence-only data in ecology. Annals of Applied Statistics 4: 1383–1402.

Welk E. 2004. Constraints in range predictions of invasive plant species due to non-equilibrium distribution patterns: Purple loosestrife (*Lythrum salicaria*) in North America. Ecological Modelling 179: 551–567.

Wickle CK. 2003. Hierarchical Bayesian models for predicting the spread of ecological processes. Ecology 84: 1382–1394.

Wilson DS, Stoddard MA, Puettmann KJ. 2008. Monitoring amphibian populations with incomplete survey information using a Bayesian probabilistic model. Ecological Modeling 214: 210–218.

Ziolkowski D Jr, Pardieck KL. 2008. North American Breeding Bird Survey: 42 Years Strong and Growing. Paper presented at the Ecological Society of America Annual Meeting, Milwaukee, WI, 7 August.

Sarah T. Bois (sarah.treanor@uconn.edu) is a doctoral candidate in Ecology and Evolutionary Biology at the University of Connecticut, Storrs, and serves as the volunteer coordinator for the Invasive Plant Atlas of New England. John A. Silander Jr. is a professor in the department of Ecology and Evolutionary Biology at the University of Connecticut, Storrs, and is the principal investigator (PI) for the Invasive Plant Atlas of New England. Leslie J. "Les" Mehrhoff was the project manager and co-PI for the Invasive Plant Atlas of New England.