Adapting Traditional Field Activities in Natural History Education to an Emerging Paradigm in Biodiversity Informatics

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Abstract

The use of Web-based informatics tools such as eBird, iNaturalist, and NatureAtlas that allow anyone to find and share occurrences and observations of organisms in nature could readily be integrated with the time-honored specimen collection and field journaling components of taxon-based natural history courses. We find, however, that fewer than 2% of such courses have used any such tool. Consequently, the far majority of students receive no formal exposure to the 21st-century technologies and concepts that are transforming the data landscapes of the very fields the courses should be preparing them to enter. We conducted a seven-year, empirical assessment of the integration of such technology with coursework, and our results reveal why recognizing and correcting this shortcoming is critical. Our data indicate that such technology can enhance student engagement and student perception of learning, and that its broader integration with coursework could be a boon to regional and global efforts to document and conserve biodiversity. We conclude that the academic community is missing a tremendous opportunity to better engage future biologists and potential citizen-scientists in a critically important, emergent paradigm in biodiversity informatics.

Key Words: *biodiversity informatics; biodiversity crisis; citizen-science; crowdsourcing; natural history education; higher education; NatureAtlas; Web 2.0.*

○ Introduction

The study and conservation of biodiversity requires accurate and precise knowledge of the composition and distribution of flora and fauna (Niemalä, 2000; Kim & Byrne, 2006; Guralnick et al., 2007; Buhlmann et al., 2009; Buchanan et al., 2011; Telenius, 2011). The growing consensus, however, is that resources in natural heritage programs and the biodiversity sciences (i.e., systematics and ecology) are insufficient alone to document and track our biota at rates sufficient to mitigate the rapidly advancing threats to biodiversity of habitat loss, invasive species, and climate change (Kim & Byrne, 2006; Wake & Vredenburg, 2008). Traditional data sources, i.e., those collected by scientists and deposited in museum and herbarium collections, are primarily historical in nature and generally do not provide the real-time rate nor volume of data acquisition necessary to counter the threats, even if such data were ever completely inventoried and made available at Web-repositories such as the Global Biodiversity Information Facility (Telenius, 2011). Invasive species, for example, likely spread at rates faster than the rate at which samples of them turn up in herbaria and museums or their databases, making the prospects for using such data for the early detection and eradication of such species unlikely before they become a problem. The same might be said about the prospects for exclusively using herbarium and museum inventories to detect and thus mitigate the negative impacts of climate change on native biota. In light of these shortcomings of traditional data sources, some biologists have looked to Web 2.0 as a strategy to harness and unify the observational power of both the scientific and amateur naturalist communities to help alleviate this crisis (Silvertown, 2009; Stafford et al., 2010; Wiersma, 2010; Barnoksy et al., 2011) and to help stave off our descent into the depths of what could be Earth's sixth mass extinction (Wake & Vredenburg, 2008; Barnoksy et al., 2011; Ceballos et al., 2015).

"Web 2.0" is a term applied to the figurative "second generation" of websites and the supporting technologies that, instead of merely disseminating content, encourage user-generated content (Alexander, 2006). The Web 2.0 site Wikipedia, for example, has grown since its inception in 2001 to be the world's largest and most widely read encyclopedia, primarily through the contributions of volunteer, amateur encyclopedists. The biodiversity Web 2.0 site eBird, for example, crowdsources more than five million new bird sightings per month, mostly from amateur birders, and has supplied data used in over 90 peer-reviewed articles and book chapters to make important discoveries regarding the spread of invasive species, the effect of climate change on avian migration, and more (Hurlbert & Liang, 2012; Bonney et al., 2014). Even websites geared mainly to the digitization and dissemination of museum and herbarium collections now sometimes feature "crowdsourcing" modules to supplement their historical specimen-based data with contemporary observations from the "crowd," which includes observations from

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amateur naturalists and those not necessarily vouchered by specimens (Gries et al., 2014). Thus, a new paradigm in biodiversity informatics is emerging, one in which the invaluable curatorial and analytical skills of scientists are integrated with the Web-2.0-enhanced observational power of amateurs in the important task of documenting and conserving our changing biota.

Given the phenomenal potential of this new paradigm and now-widely available tools (Table 1) that facilitate the traditional work of field biologists while also capturing volumes of additional, crowdsourced data, one could argue that higher education, in its preeminent role of training the next generation of biodiversity scientists, is obligated to provide formal exposure to the use and potential merits of these technologies. Yet the literature is wanting on whether this is happening and, if it is not happening, whether there are negative ramifications of any neglect in this regard. Here we present the results of a seven-year, empirical assessment of (1) the extent to which these new technologies are being integrated with university coursework in natural history, and (2) what if any assets this integration brings to the educational goals of a course or to the efforts to better understand and conserve regional biotas.

○ Materials and Methods

To What Extent are Web 2.0 Informatics Tools Being Integrated with Traditional Coursework?

To determine the extent to which Web 2.0-enabled tools were being used with traditional field-based collection projects or journaling projects, we conducted a survey of 60 taxon-based university courses in subject areas (i.e., entomology, ornithology, and plant taxonomy) that have historically had strong field components that would lend themselves to the use of such technology, namely locating and identifying organisms in the field. We limited ourselves to courses taught between 2010 and 2015 because this was the same period that our empirical study with our own student projects (described below) was taking place and during which Web 2.0 tools like those listed in Table 1 had been widely available. Google searches were used to obtain syllabi on the Web for courses in these three subject areas on June 5, 2013 (10 syllabi for each course type) and again on July 15, 2015 (an additional 10 syllabi for each course type). Searches were performed by searching on the name of the course type plus the term "syllabus" (e.g., "plant taxonomy syllabus").

Chosen for review on each date were the first 10 syllabi found for each course type that also met four criteria: (1) being contemporary with the term of our study (i.e., Spring 2010 or later); (2) having a lab component; (3) being sufficiently detailed to discern the type and scope of projects assigned; and (4) that the syllabus or course described not be a duplicate of one assessed earlier. This quasi-random survey was thus limited to syllabi written in English and posted openly on the Web; the survey was unable to detect syllabi not posted on the Web or those posted only on private, password-protected course-management servers. This survey also did not specifically target websites such as those listed in Table 1, where specific projects or specific courses using such tools might have been listed, since doing so would have skewed our survey results and precluded any attempt to generalize about what was happening in higher education at large.

Of What Value is the Integration of Web 2.0 Informatics Tools? An Empirical Assessment

The empirical assessment of the value of using Web 2.0 tools with course-related field activities was done with plant collection projects in seven annual offerings of *Plant Systematics (BIOL 325)* at Millersville University of Pennsylvania. BIOL 325 was offered with two hours of lecture and three hours of laboratory weekly for 15 weeks, typically to between 21 and 24 students every Fall Semester (with the exception of a Spring Semester offering in 2010). During the seven semesters reported here (Spring 2010 and Fall semesters of 2010, 2011, 2012, 2013, 2014, and 2015), BIOL 325 was taken largely (n = 155 students) by seniors (76%), followed by juniors (20%) and sophomores (4%). Most students were biology majors (i.e., 95%, Table 2). The collection project was worth 15% of each student's total course grade, with the mean grade on the project being a B (85%) and the mean whole-course grade being a C+ (78%).

The project required each student to collect 10 flowering, fruiting or sporing specimens of wild plants from 10 different species and to preserve and mount them as herbarium specimens for deposition in the university's James C. Parks Herbarium (Appendix 1,

Table 1. Web 2.0-enabled informatics sites,* which allow users to log at least basic data about the occurrences of species (ordered alphabetically). NatureAtlas was the site used for the study reported on in this article

Site	Web Address	Taxonomic Focus
eBird	www.ebird.org	Birds
EDDMaps	www.eddmaps.org	Invasive Species
iMapInvasives	www.imapinvasives.org	Invasive Species
iNaturalist	www.inaturalist.org	Animals, Fungi, Plants, etc.
iSpot	www.ispotnature.org	Animals, Fungi, Plants, etc.
NatureAtlas	www.natureatlas.org	Animals, Fungi, Plants, etc.
Project Noah	www.projectnoah.org	Animals, Fungi, Plants, etc.

*This list does not include other sites geared primarily to the collection and dissemination of herbarium or museum specimen data, some of which have recently also implemented crowdsourcing functionality, which allows observations not vouchered by specimens.

Table 2. Degree-seeking status of the 155 students who participated in the collection projects over the course of seven semesters of *Plant Systematics (BIOL 325)* at Millersville University of Pennsylvania.

Degree Sought and Major	Number of Students	Percentage
Bachelor of Science (or Arts)—Biology	147	94.8
Bachelor of Science Education—Biology	3	1.9
Bachelor of Arts—Geography	2	1.3
Bachelor of Science (or Arts)—Chemistry	1	0.6
Bachelor of Science Education—Earth Sciences	1	0.6
Bachelor of Arts—Psychology	1	0.6

Figure 1. Users of NatureAtlas are prompted with a new record entry box when clicking on the interactive map with their mouse or touch pad. The entry box shown here is the result of a click by the user on a spot in the Millersville University Biological Preserve adjacent to the Conestoga River in Lancaster County, Pennsylvania. The entry box is populated with 26 data fields, nine of which must be entered upon submission and the rest of which are available if the instructor wishes to require them (the entry box is reduced in complexity when using a smartphone). It is not anticipated that a student will have access to all the data required for all fields at the time of their initial record submission, so a record edit function (not shown) is available that allows a student to add to or revise a record's content (e.g., a taxonomic determination or locale element) at a later time.

but also see Appendix 2 for a similar type of project in which only photos are used to voucher observations). The descriptive details required for the herbarium specimen label (family, species, locality, plant and habitat description, and collector and collection identity number) were entered and mapped by the student first into NatureAtlas (www.natureatlas.org, Hardy & Hardy, 2016), after which labels for affixing to the herbarium specimens were prepared and printed from NatureAtlas according to the procedure described in the online user manual for NatureAtlas. The physical herbarium specimens provided a means by which the course instructor could verify the accuracy of the students' taxonomic determinations of their records.

NatureAtlas is a Web-based biodiversity geographic information system that allows anyone to contribute or download georeferenced observations and photos of organisms, generate interactive biotic inventory atlases, generate distribution maps, generate specimen labels, and explore biodiversity. One does not need to be part of any class or project to log on and add or search records in NatureAtlas; however, the site was launched in 2008 with the needs of instructors and students in field-oriented natural history courses in mind. Among the education-oriented design elements employed is a data-entry interface (Fig. 1) that (1) allows a user to add observations simply by mouse-clicking on the interactive map at the location where an organism was found (i.e., the added expense of a portable GPS-enabled device is not required), and (2) provides structure to the data entry process at a level of sophistication that would be expected of an undergraduate biology student (i.e., there are multiple, hierarchically nested taxonomy and location fields

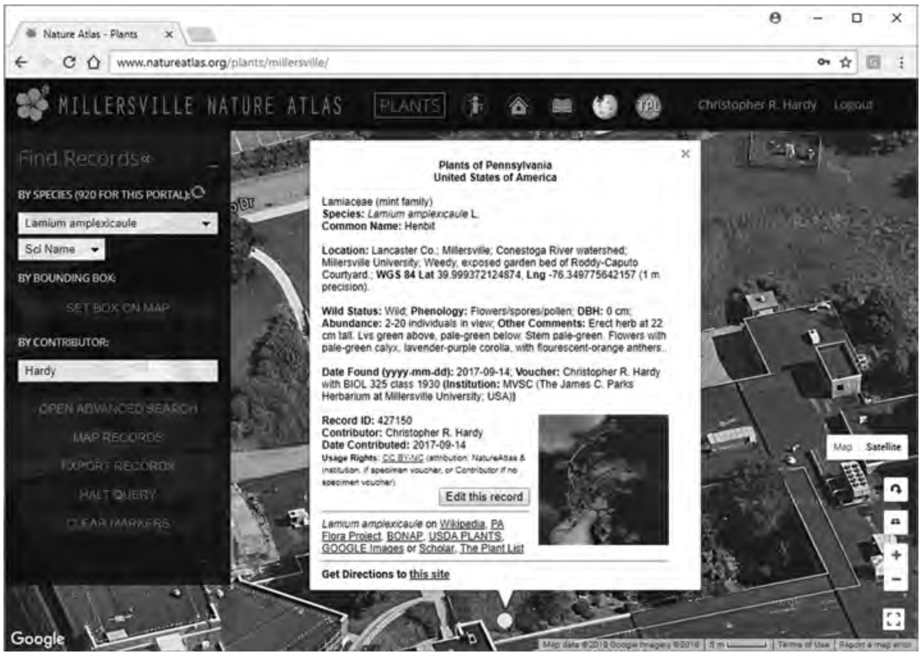

Figure 2. In this screenshot, a user has searched on a plant species, *Lamium amplexicaule*, and clicked on one of the resulting location markers for that species. The resulting information box that appears following the click contains the data entered by the contributor of that record in addition to dynamically generated links to third-party sites for additional information on that species—sites including Wikipedia, the Biota of North America Program, the United States Department of Agriculture's PLANTS database, Google Images, and Google Scholar. A photo taken of that plant, if present, is also displayed in the lower right of the information box.

available for entry: the instructor determines which if not all of the fields are required for a project). Once entered, the record marker can be clicked with the computer mouse to display a pop-up information box containing the data entered for that record as well as dynamically generated links to authoritative third-party sites for additional information on that species, information such as county- and state-level distribution maps from the Biota of North America Program and primary literature using Google Scholar (Fig. 2).

Although the general user can access NatureAtlas through any of eight global, taxon-specific portals (i.e., Birds, Fishes, Fungi, Herps, Invertebrates, Mammals, Plants, and Zooplankton), the NatureAtlas user manual describes how anyone (e.g., course instructor) can, if desired, create a custom subportal for their project (www.natureatlas.org/all/manual/). A custom subportal is not necessary for a project, but it does facilitate specific projects by (1) setting the default zoom level of the map to the specific geographic scope for the project, (2) having the species-search box keep a running checklist of the species found only in that particular geographic area, and (3) auto-filling subportal-specific information into the new record's entry form to expedite data entry. The Millersville Plants subportal (www.natureatlas.org/plants/millersville/), for example, was created to serve as the primary portal through which students in this study were able to enter their records as part of their plant collection projects. For each species, a custom link was available through this subportal to the regional flora authority, the Pennsylvania Flora Project, which allowed our students to quickly ascertain the state-level conservation and nativity status of their species and to supplement the Biota of North American Program link in determining whether their entries constituted new state or county records for their species (Fig. 2). Although there are now a variety of similar tools available to students and educators (Table 1), we chose to use NatureAtlas for our study primarily because (1) it provided the structured data-entry and specimen label-printing functions desired for use with our plant-collection project, and (2) it had already been in use since 2008 as our herbarium's specimen data repository.

As student projects were completed, students' herbarium specimens were examined by the professor (CRH) for both determining student grades and assessing the frequency of accurate taxonomic determinations. If a taxonomic determination was inaccurate, it was corrected by the professor immediately both on the herbarium specimen label and in the NatureAtlas database using NatureAtlas's edit function for the sake of accuracy and posterity. By doing so, the professor could ensure that all student records entered into NatureAtlas were taxonomically accurate. After the accuracy of records was verified, we exported all student records as a spreadsheet from NatureAtlas (using the its export function) and then shared the data with the data managers of relevant regional informatics projects, namely the Biota of North America Program (www.bonap.org), the Pennsylvania Flora Project (www.paflora.org), and by extension, the developing Mid-Atlantic Herbarium Consortium of which the Pennsylvania Flora Project is a contributing member organization (http://midatlanticherbaria.org/portal/). Although data at NatureAtlas were already publically accessible on the Web, we thought that sharing our data with these additional informatics projects would make these data more broadly accessible to potential users of these data.

Locational accuracy of student records was also assessed. Since, with more than 1,500 records, it was not feasible to visit the reported localities of all student records, in the summer of 2011, we conducted a location-verification study on the woody plants subset (64 in total) reported for the 12-hectare Millersville University Biological Preserve during the Spring 2010 and Fall 2010 semesters, and we did this after taxonomic determinations were verified and, if necessary, corrected by the professor. Woody plants were chosen because such plants have perennial, above-ground parts that were more likely than those of herbaceous plants to have remained in place up to a year and some months after their localities were reported by the students. With this list of 64 woody plants, a Garmin eTrex Vista GPS unit and a printing of the mapped locations from NatureAtlas were used to visit each reported locality to determine if a plant of that species could be found within a 25 m radius of that precise location. If so, then the record was deemed to be geospatially accurate.

To determine if the frequency of successful finds was significantly better than random, we divided the Biological Preserve where these 64 plants were reported into fifty 50 x 50 m quadrats, and then randomly reassigned the same 64 records each to the center of a randomly chosen quadrat. Random quadrat assignments were made by first assigning a unique number to each of the quadrats, and then using the random number generator in Microsoft Excel to randomly assign a quadrat number between 1 and 50 to each plant in the original list of 64 plants. We then visited these random localities to see if a plant of that species could be found within a 25 m radius. We then used a Fisher's Exact Test on a 2 x 2 contingency table of random (null) vs. non-random (student-reported) localities by successful vs. unsuccessful finds to determine if the success rate of species finds at the student-reported localities was significantly better than random.

To gauge the response of the students to the project as a whole, including the Web 2.0 aspect, we administered an anonymous, voluntary survey of nine questions to students in class after their projects were completed but before they received their project grades. Anonymity was maintained by the professor (CRH) leaving the room while the students completed the survey. The students did not write their names on their completed surveys. After the surveys were completed, a student volunteer collected the surveys, placed them into a sealed and appropriately labeled envelope, and delivered them to the Biology Department Secretary for safe keeping until after the close of the semester and all final grades had been submitted by the professor.

○ Results

Outcome of the 60-course Survey to Assess the Extent to which Web 2.0 Informatics Tools are Being Integrated with Traditional Coursework

We found that a large percentage of the 60 courses we surveyed (72%) required at least the traditional specimen collection or journaling project (Table 3, Appendices 3–5). However, we found that less than 2% (one of 60) had students deposit their field observations or specimen data into a digital public data repository. That one course was an ornithology class that had its students submit their field observations to eBird.org (Appendix 5). None of the 20 plant taxonomy or 20 entomology courses surveyed used any such tool.

Outcome of the Plant Collection Projects

Following seven course offerings over seven academic years, 155 undergraduates contributed 1,537 new and original locality records for 305 species. All records and associated data were entered by students into NatureAtlas, and each was vouchered by a herbarium specimen deposited by each student in the James C. Parks Herbarium at Millersville University (available for interactive mapping and download at www.natureatlas.org/plants/earth/ or available from the authors upon request). Of these 1,537 specimens, 81%, 93%, and 97% were accurately identified to species, genus, and family, respectively. Incorrect identifications were corrected by the course instructor on both the herbarium specimen label and in NatureAtlas during the process of his grading each collection project.

The locality verification study of a subset of these records found them to be highly and significantly geospatially accurate. Of the 64 woody plants reportedly collected in the Millersville University Biological Preserve, we were able to locate the reported species within a 25 m radius of the reported latitude and longitude in

Table 3. Undergraduate biology curricula have generally not yet integrated laboratory and field experiences with biodiversity informatics tools that incorporate Web 2.0 technologies.*

Course type (n = 20 for each)	Number of courses surveyed	Collection project	Specimen preparation (includes labels at minimum)	Field notebook that includes sightings	Private databasing (not available on the Web)	Public databasing (data sharing on the Web)
Plant Taxonomy	20	16	11	6	3	0
Entomology	20	18	18	1	1	0
Ornithology	20	0	0	9	0	1
Totals	60	34 (57%)	29 (48%)	16 (27%)	4 (7%)	1 (<2%)

*This table summarizes the data from our review of 60 undergraduate courses with labs in Plant Taxonomy, Entomology, and Ornithology taught between 2010 and 2015, the same period in which our empirical study in our own course was taking place. Appendices 3–5 provide the raw data and actual courses from which these data were derived. The results indicate that "collection projects" are typical in Plant Taxonomy and Entomology, where students are required to collect, identify, and preserve specimens from some specified number of wild plants or insects. Paper labels for each preserved specimen that contained information about the identity, location, and collection date were usually also required. Field notebooks, journals, or reports containing written observations in lieu of actual collections were preferred in Ornithology.

60 of 64 instances (Appendix 6). When these same records were assigned to random locations within the Preserve, we were able to find the respective species in only 42 of 64 cases. We used a 2 x 2 contingency table of random (null) vs. non-random (student-reported) localities by successful vs. unsuccessful finds to reveal that the 66% success on random localities was significantly worse than the 94% achieved with non-random localities (Appendix 6, $p = 0.0000556$, Fisher Exact).

Of the 1,537 records, two were new state records and 31 were new species records for counties in the United States (Table 4). Of these 31 new county records, 11 were for exotic species classified by state agencies either as Invasive, Noxious, or Watch List (Table 4).

Outcome of the Anonymous Student Surveys

Anonymous, post-project surveys administered to the students indicated that a majority of students found the project enjoyable (102 of 121 respondents, Question 1 in Table 5) and educational regarding the local flora (117 of 121 respondents, Question 2) and geography (71 of 121 respondents, Question 3). Most students believed that the digital tools of NatureAtlas made the project more enjoyable (82 of 120 respondents, Question 4), more educational regarding the local flora (85 of 121 respondents, Question 5) and geography (74 of 120 respondents, Question 6) than without the digital tools. A majority of students found NatureAtlas to be easy to use (105 of 120 respondents, Question 7), and reported that they would probably use

Table 4. Seven semesters of student projects produced 31 new state or county records for 29 species.*

Species	Vernacular	New State	New County	State Status
Natives				
1. *Amorpha fruticosa*	false-indigo		York (PA)[1]	
2. *Desmodium canescens*	hoary tick-trefoil		York (PA)[1,2,3]	
3. *Hibiscus moscheutos*	rose-mallow		York (PA)[1,2,3]	
4. *Liquidambar styraciflua*	sweetgum		Lancaster (PA)[1,2,3]	
5. *Ludwigia peploides*	primrose-willow		Dauphin & York (PA)[1,2,3]	
6. *Oenothera biennis*	evening-primrose		York (PA)[1]	
7. *Pontederia cordata*	Pickerel-weed		Montgomery (MD)[1,3]	
8. *Rudbeckia triloba*	brown-eyed Susan		York (PA)[1]	
9. *Symphyotrichum praealtum*	veiny-lined aster		Lancaster (PA)[1,2,3]	
Exotics				
1. *Albizia julibrissin*	mimosa		Lancaster (PA)[1,2,3]	Invasive
2. *Catalpa speciosa*	northern catalpa		Lancaster (PA)[1,2,3]	
3. *Celastrus orbiculatus*	Oriental bittersweet		York (PA)[1,3]	Invasive
4. *Datura stramonium*	jimsonweed		Harford (MD)[2,3], Perry (PA)[1,2,3]	Invasive; Noxious Weed
5. *Euonymus alatus*	burningbush		York (PA)[1,2,3]	Invasive
6. *Euonymus fortunei*	wintercreeper		Lancaster (PA)[1,2*,3]	Invasive
7. *Euonymus japonicus*	Japanese spindletree	PA[1,2,3]	Lancaster (PA)[1,2,3]	
8. *Hieracium lachenalii*	European hawkweed		Lancaster (PA)[1,2,3]	
9. *Lespedeza cuneata*	bush-clover		Lebanon (PA)[1,2,3]	
10. *Lonicera maackii*	Amur honeysuckle		Lancaster (PA)[1,3]	Invasive
11. *Malus baccata*	Siberian crabapple		Lancaster (PA)[1,2,3]	
12. *Malus prunifolia*	Chinese crabapple		Lancaster (PA)[1,2,3]	
13. *Pachysandra terminalis*	Japanese pachysandra		Lancaster (PA)[1,2,3]	Watch List
14. *Persicaria longiseta*	bristled smartweed		Schuylkill (PA)[1,2,3]	Invasive
15. *Phyllostachys aureosulcata*	yellow-groove bamboo	PA[1,3]	Lancaster (PA)[1,2,3]	

Table 4. Continued

Species	Vernacular	New State	New County	State Status
16. *Pyrus calleryana*	Callery pear		Lancaster (PA)[1,2,3]	Invasive
17. *Rhodotypos scandens*	jetbead		Lancaster (PA)[1,2,3]	Invasive
18. *Senecio vulgaris*	common groundsel		Lancaster (PA)[1,2,3]	
19. *Taxus baccata*	English yew		Lancaster (PA)[1,2,3]	
20. *Viburnum dilatatum*	Linden arrowwood		Lancaster (PA)[1,2,3]	Watch List

*Eleven (55%) of the exotic species are species listed as Invasive, Noxious, or Watch List species (i.e., potentially invasive) by the Pennsylvania Department of Conservation and Natural Resources (http://www.dcnr.state.pa.us/). State abbreviations are PA for Pennsylvania and MD for Maryland, USA. New state or county records were assessed based on the Pennsylvania Flora Project (www.paflora.org, denoted by the superscript 1 following the state or county), the Biota of North America Program (www.bonap.org, denoted by the superscript 2), or the United States Department of Agriculture's PLANTS database (http://plants.usda.gov/, denoted by the superscript 3). *Phyllostachys aureosulcata*, for example, had been listed for Pennsylvania by the Biota of North America Program (source 2) but had not been listed for the state by the Pennsylvania Flora Project (source 1) or the USDA (source 3); thus, it is denoted as a new state record by the abbreviation PA[1,3].

Table 5. Anonymous, post-project student survey results.*

Question	Number of Responses by Score					Mean Score 1–5
	Strongly Disagree 1	Disagree 2	Neutral 3	Agree 4	Strongly Agree 5	
1. I found this project enjoyable.	0	2	17	64.5	37.5	**4**
2. I learned about our local flora on this project.	1	1	2	50	67	**5**
3. I learned about the geography of the Millersville region from this project.	1	19	30.5	47.5	23	**4**
4. The digital NatureAtlas.org component of this project made the project more enjoyable.	1	5	32.5	59.5	22	**4**
5. The tools at/of NatureAtlas.org made it easier to learn about the local flora.	1	4	31	60	25	**4**
6. The tools at/of NatureAtlas.org made it easier to learn about the local geography.	1	11	34	45	29	**4**
7. I found the NatureAtlas.org website to be easy to use.	1	3	11	56	49	**4**
8. I will probably use NatureAtlas.org in the future.	5	10	34	51	18	**4**
9. After this project, I am more likely to notice plants when I am outdoors.	0	1	0	24	93	**5**

*This survey of nine questions was voluntarily completed as described in Materials and Methods by 121 of the total of 155 students over the seven course offerings between 2010 and 2015. 34 students chose not to participate or were absent in class on the day that the survey was given. Scoring options for each question were 1 (strongly disagree), 2 (disagree), 3 (neutral), 4 (agree), and 5 (strongly agree). Each student was instructed to select only one number for each question, and the raw numbers of responses for each response category are indicated. All 121 students responded to most questions; however, a few students did not respond to some questions, for reasons unknown. Thus, the raw counts for some of the questions sum to less than 121. Half-counts (".5") were recorded when a student circled two options rather than one; for example, when a student circled both "Agree" and "Strongly Agree," a count of 0.5 rather than 1 was assigned to each of those categories.

NatureAtlas in the future (69 of 118 respondents, Question 8) and that the project made them more likely to notice plants when outdoors (117 of 118 respondents, Question 9).

○ Discussion

Although getting students outdoors to observe and identify species are still important components of natural history education, course curricula in this regard appear to be lagging behind 21st-century advances in informatics technologies and concepts. For nearly two decades, the World Wide Web, along with geolocation tools and software, has facilitated institutional efforts to digitize and provide global access to museum and herbarium specimen records accrued largely by professional biologists over the last two centuries. Such efforts were conceived on the basis that the greatly increased accessibility of data via the Web would in turn fuel efforts to better study, manage, and conserve biodiversity.

More recently, tools emerged that reformulated the Web-based informatics paradigm to include data that could be collected, shared, and mapped in real time and by both professional and amateur naturalists alike (Table 1). This so-called Web 2.0 approach to biodiversity informatics has been a demonstrable success, greatly increasing the rate, timeliness, and geographic specificity of data acquisition, which in turn has led to important discoveries regarding phenomena ranging from the spread of invasive species to the effect of climate change on native species (Hurlbert & Liang, 2012; Bonney et al., 2014). Yet despite the widespread availability, use, and apparent importance of such tools, we found that less than 2% of commonly offered natural history courses with lab components use any such tools in concert with field activities that would readily lend themselves to their use (Table 3), and our review of the literature indicates that the impact of their use as such has not been the subject of published analysis. Consequently, most future scientists enrolled in such courses see their observations of species that they generated during the course effectively discarded and are then left alone to later discover and navigate the new data landscape ad hoc.

Perhaps the reason for the neglect to formally integrate such technologies into coursework is simply generational. After all, these sites have only been around and global in scope for approximately 10 years or less. It is therefore possible that a higher proportion of the younger cohort of biologists will integrate them as they assume roles as professors and instructors in the relevant courses. It is also possible that some instructors believe that integrating new technologies comes with the added burden to change the way they have been doing things, or the burden of dealing with unforeseen challenges of training students to use yet another tool, or with technical difficulties that could arise mid-semester, such as the website going down. Or perhaps there are those instructors who, despite recognizing the potential vocational value of exposing students to the use of such tools, have doubts about the quality of data their students would be posting on the Web and thus sharing with the world. We are largely speculating on the reasons instructors may have; however, we do have seven years' worth of empirical data that might dispel such concerns.

Our data were derived from our use of one such tool, NatureAtlas, with an otherwise traditional plant collection project in a junior-senior-level plant taxonomy course for seven semesters spanning 2010 through 2015. Anonymous, post-project surveys administered to our students indicated that a majority of students found the project enjoyable (84% of 121 respondents, Question 1 in Table 5) and educational regarding the local flora (97%, Question 2). Of our students, 99% indicated that, because of this project, they were more likely to notice plants when they were outdoors in the future (Question 9). These statistics do not explicitly address the technological aspects to this project, but do indicate strongly that collection or journaling projects can be important components of taxon-based natural history courses, since they help accomplish the core course objectives of increasing knowledge of, awareness of, and appreciation for the taxon of study.

Regarding the digital and Web 2.0 components of this project in particular, our surveys revealed that most students believed the added technology was easy to use (88%, Question 7) and made the project more enjoyable (68%, Question 4) and more educational regarding the local flora (70%, Question 5). A majority of students expected to use or contribute to the digital atlas in the future on a voluntary basis (58%, Question 8). These data indicate that the project had accomplished the very important objectives of raising awareness and appreciation for the value of these technologies and their capacity to enhance efforts in the study and conservation of biodiversity. These data also indicate that the classroom is more than a mere training ground for future biodiversity scientists; it also is a potential recruiting ground for future citizen-scientists.

We have no hard data to address the notion that some instructors may have about the added technology being a burden to integrate with field projects, except to report that we have found the use of NatureAtlas to facilitate rather than complicate the specimen collection project that was already an important and recurring component to the plant taxonomy course reported in this article. Students were already making plant collections for inclusion in our university herbarium. By employing NatureAtlas, we then had a single common database that could be accessed by each student remotely from any computer via the Web. As students entered their specimen data, their data were at once georeferenced and logged into our own institutional database, since we already had used NatureAtlas as such. Gone were the days of receiving separate emails from each student with data contained in spreadsheet or jpeg image attachments. Gone was the need for the instructor to concatenate the separate sets of student data together into a common spreadsheet, since they were already in NatureAtlas and could then be readily be retrieved, mapped, and if desired, even downloaded as a spreadsheet by the instructor. Gone was the need to have the students reenter their data into word processor documents and then endeavor to format their data for the printing of specimen labels since NatureAtlas did that for them. For readers, we have provided the description of the project that we give to our students as an appendix to this article (Appendix 1). We have also provided a version of it that might be used for a vertebrate-focused course where photos rather than specimens are used to voucher student observations (Appendix 2).

Regarding negative preconceptions had by course instructors about the quality or value of student-generated data: our data refute such preconceptions. Although the Pennsylvania flora is large and complex, with over 3,000 species, our students were able to make accurate taxonomic determinations to species, genus, and family in 81%, 93%, and 97%, respectively, of their records. Locality verification of a subset of the records found them to be highly and significantly geospatially accurate ($p = 0.0000556$, Fisher Exact Test on data found in Appendix 6). These levels of accuracy are high and, at minimum, fall within the range for what may generally be available from existing data portals that serve largely museum and herbarium specimen locality records and are considered to be "science-grade" in quality (Meier & Dikow, 2004). The use of Web applications that employ social networks to help users with photos identify their organisms would likely further increase the accuracy of taxonomic determinations (Silvertown et al., 2015). In fact, the accuracy of student-generated occurrence data should generally, as in this study, approach 100%, as the professor corrects inaccuracies in the students' website entries in the course of grading the projects.

As for value in the data, the records contributed during our study represented new and original locality records for 305 species. Of these, two were new state records and 31 were new species records for counties in the United States (Table 4). Of these 31 new county records, 11 were for species classified by state agencies either as Invasive, Noxious Weeds, or Watch List species (Table 4). Such discoveries are facilitated through the use of Web applications like NatureAtlas because each record is linked with distributional information and conservation rankings from other Web-based, regionally relevant biodiversity informatics websites. The use of a tool like NatureAtlas also facilitates the rapid dissemination of such discoveries to the broader user community because (1) the data are immediately and publically available on the Web, and (2) the data, already in a digital format and downloadable, can be easily shared with regional natural heritage programs or biotic informatics projects as desired. This project thus became more than just another class project for the students, since it had contributed valuable new knowledge about the regional flora. This may not be surprising to professional taxonomists or ecologists, since they have long known that there are always new discoveries to be made, even locally where the flora is relatively well known (Prather et al., 2004). However, it often comes as an epiphany to students, who do not enter a class expecting to make important new discoveries in their own backyards or to contribute to regional conservation efforts. Given, therefore, the potential quality and value of course-generated data in this regard, it is surprising that more courses have not yet adopted technologies that would increase the accessibility of such data.

We acknowledge, however, that such levels of taxonomic accuracy may not always be possible. Factors contributing to the high levels of taxonomic accuracy seen here include the fact that the Pennsylvania flora, although large and diverse, is well-characterized, and all students in this course had their own copy of a published manual to the flora, *The Plants of Pennsylvania* (Rhoads & Block, 2007), in which dichotomous keys and descriptions of each and every species were available. Botany students in other states with floras less well-known and for which no manual has been published may find it more challenging to identify species, and lower levels of taxonomic accuracy could be the consequence. The extent to which similar levels of taxonomic accuracy might be observed for other organism types, such as birds or mammals, also is not known since our study was carried out only on plant taxa. On the one hand, the bird and mammal faunas should generally be relatively small, well characterized, and thus potentially tractable in their identification (e.g., there are only approximately 450 and 64 species of birds and mammals, respectively, in Pennsylvania). On the other hand, ethical and legal restrictions will preclude the collecting or handling of bird and mammal specimens, as can be done with plants to facilitate a positive species determination.

In lieu of voucher specimens, however, voucher photographs can and should be uploaded with bird and mammal records for such assignments: not only do they serve to provide the student with a nearly complete experience on what it takes to document scientific observations of organisms (i.e., identifying the taxon, describing and photographing the organism), but they also enable the course instructor to verify the species and, potentially, sex of the animal reported by a student. At a time when most if not all students will own a camera-equipped smartphone, it is reasonable for a course instructor to expect that each student can generate 5 to 10 observations and 5 to 10 quality photographs of birds or mammals over the course of a two-month project duration (i.e., the time given for our plant collection project). If a photograph is of a quality insufficient for even the professor to make a positive taxonomic determination on during the grading process, then the professor should remember that the burden of submitting a quality photograph rests with the student and so the student's grade should, in part, reflect the quality of the photograph.

Insects, of course, comprise an extremely diverse and taxonomically difficult clade for which the only available taxonomic keys are often incomplete and resolve only to the family or genus level. Nevertheless, there are certain guilds of insects that are more well-known than others (e.g., pollinators) that could be targeted by such a project and for which positive identifications down to genus if not species should be possible and verifiable by the instructor during the grading process, especially if no more than 10 records are required of the students. Although many traditional journaling or collection projects in entomology courses call for observations or specimens numbering in excess of 50, professors considering the injection of Web 2.0 tools and the added requirement of photographs should consider either reducing the required observation/specimen count or conducting a hybrid project in which only a fraction of the 50 observations or specimens, for example, are required to be photographed and submitted using the Web tool. Whatever the incoming levels of accuracy produced by students, the course instructor should be able to correct erroneous identifications during the grading process so long as he or she has (1) limited the requisite number of records to be submitted by each student, and, where necessary, (2) called for some appropriate form of vouchering, such as photos or specimens, and (3) provided guidance on the types of insects to be recorded (e.g., pollinators are among the more readily identifiable at lower taxonomic levels for most students). Thus, the outcome of the semester projects could and should be new and original species or genus occurrence records available to the world on the Web.

In conclusion, we have demonstrated the need for a value-added merger of Web 2.0 and biodiversity informatics with traditional field assignments in natural history higher education. Instructors benefit from the utilization of tools that simplify their management and digital archiving of student-generated data. Universities benefit by seeing their lab-based courses elevated in importance through their provision of accessible, valuable data to regional efforts to document and conserve biodiversity. Students benefit by learning how to conduct field work and to record data in a digital, geospatially explicit format. Students learn that their regional biota is dynamic and under threat by various factors including the advancement of non-native species, which, in our study, comprised the majority of new county or state records (Table 4). They learn that it is no longer necessary nor acceptable in the Information Age to relegate their hard-sought field data to the obscure annals of publically inaccessible grade books, handwritten personal journals, or museum collections where they sit for decades or more unutilized. These students, who are our next-generation systematic biologists, ecologists, and citizen-scientists, are left with the realization that the more eyes we have on nature, the better prepared we are to manage and conserve nature. Students must be shown that Web 2.0-enabled tools like those described in Table 1 are important new tools in the broader, multipronged effort to better document biodiversity, mitigate the biodiversity crisis and to conserve our natural heritage.

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CRH and NWH conceived of and directed the design of NatureAtlas.org. CRH was the course instructor responsible for the design, implementation and grading of the plant collection projects and anonymous student surveys reported on in this study. Both CRH and NWH were responsible for compiling relevant statistics and for writing this article.

Data Accessibility: All plant locality records discussed and referenced in this article are available at www.natureatlas.org/plants/earth/ and can also be made available directly upon request.

Appendix 1. Sample project announcement where records are vouchered by both specimens and photographs. In the class for which data are presented in this article, the project was worth 15% of the total course grade and was equal to one midterm exam in points; thus, one can scale these point values up or down accordingly if adopting a similar weighting scheme. Although the geographic scope of our project always centered on Millersville (the town surrounding the university), later years in our seven-year study permitted students to expand their scope beyond Millersville as the town's flora became increasingly well-known.

Floristic Inventory Project (200 pts)

Towards the collective goal of knowing and mapping the flora of Millersville, your task is to make a collection and preparation of 10 herbarium specimens (to total 10 separate species) from wild plants in Millersville. All materials (the physical, mounted specimens, photographs, and their mapping on www.natureatlas.org, hereon as NA) are due in two months' time at 5:30 pm on Nov 3 (late projects deducted 10% per 24 hr period).

A. Important Notes Regarding Academic Honesty:

1. Work to identify these alone.
2. Do not team up with others to collect the "same" things. Although you can go out into the field with a classmate as a travel companion, you cannot collect the same species from those localities, and you cannot help each other with the identifications.

B. Important Procedural Notes:

1. You must keep a field notebook that describes all necessary information and this information must be taken at the time of collection. Your memory is not good enough otherwise and the Herbarium does not want specimens with faulty data.
2. There can be no collections from any population that we identified to species together as a class, such as during a lab.
3. You will not receive credit for records which duplicate the species of another of your records for this project.
4. Collect only wild plants. Do not collect cultivated plants (e.g., from a garden or cultivated landscape, unless it is a weed there).
5. You must press your plants between folded newsprint that is labeled with your name and collection number in the lower right corner on the outside so your instructor can determine whose they are since s/he will be processing them for drying and then will distribute them back to you once dry. Unlabeled specimens will not be accepted for drying.
6. You may not collect on private property without the permission of the owner.
7. You may not collect in any state or national park or forest without the proper collecting permits.
8. You may not collect plants within 5 m of a trail.
9. For herbaceous plants, you may not collect the only plant in a population or remove plants from a small population (e.g., 20 plants or less). For larger plants (e.g., shrubs and trees), you may collect a cutting from the only plant in a population that will fit a herbarium sheet, so long as the removal of that cutting is not so large as to negatively affect the chances of that plant's survival or reproductive success.
10. Information on special concern plants that are off-limits for collection will be described in class by your instructor.

C. Each Species is Worth 20 pts as Follows (point values in parentheses indicate potential deductions for insufficiencies):

1. **NatureAtlas.org Entry**
   a) Accuracy of pushpin marker placement (4 pt)
   b) Completeness and accuracy of information: all NA fields excluding "voucher comments" are required for this project (1 pt ea)
   c) Entry information must match precisely the information on the herbarium specimen label (1 pt ea)
   d) Photograph of the plant: must be of that plant and must be your own photo (2 pt)

2. **Herbarium Specimen** (unmounted, unlabeled or not completely dried glue or specimens receive no credit)
Label (follow the format and instructions for making labels in NA users' manual online):
   a) On acid-free paper? Glued well? Positioned correctly? (1-4 pt ea)
   b) Taxon Block: All fields required; species, genus, and family IDs (2 pt ea), species or subspecific author (1 pt ea)
   c) Location Block: Country, State, County, Municipality, Watershed, Locale Description, and Coordinates required; Park or Campus name if appropriate (1 pt ea)
   d) Organism Block: All fields required; Wild status, Phenology, DBH (incl. 0 cm when not reaching BH), Abundance, Description (e.g., height, color of leaf, stem, flower, or fruit) (1 pt ea). Of the plant at that locality: not a description out of a book, etc.
   e) Formatted correctly? Did you use the template file to make them? (1-2 pt)
1. **Specimen:**
   a) Stem and leaves present at minimum? (No credit if not)
   b) Roots and all of plant present for plants small enough to fit onto sheet? (to 8 pt deduction)
   c) Is the specimen fertile? (6 pt)
   d) Flower, fruits, or sporangia: Exposed and clearly pressed? Attempt made to display one as dissected for educational value on herbarium sheet? (2 pt)
   e) At least one of the leaves and the reproductive parts (e.g., fruit or flower) should be attached to the stem to show how they are attached. (1 pt ea)
   f) Leaves: top and bottom surfaces visible; pressed flat, spread apart and uncluttered (1 pt)
   g) Does the specimen fit the sheet (it should not hang off of the sheet)? (1-4 pt)
   h) Was the specimen dried properly in a press (i.e., not wrinkled, etc.)? (to 8 pt deduction)
   i) Glued well? Thicker parts will take more glue or sewing. (to 8 pt deduction)

D. Fieldbook Check: Your instructor reserves the right to ask for and check through your field notebook and to deduct up to 20 points if it is not complete.

Appendix 2. Hypothetical project announcement where records are vouchered by photographs only. In the class for which data are presented in this article, the project was worth 15% of the total course grade and was equal to one midterm exam in points; thus, one can scale these point values up or down accordingly if adopting a similar weighting scheme.

Bird Inventory Project (200 pts)

Towards the collective goal of knowing and mapping the avian fauna of Millersville, your task is to record geospatially explicit observations and photographs of 10 wild birds from Millersville. These generally must add up to 10 separate species but, if any two observations are of the same species, then they must be from different sexes and/or life history stages. All materials (the photographs and their mapping on www.natureatlas.org, hereon as NA) are due in two months' time, at 5:30 pm on Nov 3 (late projects deducted 10% per 24 hr period).

A. Important Notes Regarding Academic Honesty:

1. Work to identify these alone.
2. Do not team up with others to record the "same" things. Although you can go out into the field with a classmate as a travel companion, you cannot record the same species from those localities, and you cannot help each other with the identifications. Do not swap photos and information with others to achieve your record quota.

B. Important Procedural Notes:

1. You must keep a notebook that describes all necessary information and this information must be taken at the time of the observation. Your memory is not good enough otherwise and records with poor or faulty information are not worthy of the Inventory Project.
2. Do not record captive birds, only birds in the wild.
3. Do not remove material from or disturb or handle the animal or its nest.
4. You will not receive credit for records which duplicate the species and sex of another of your records for this project.
5. Do not venture onto private property without the informed permission of the owner.
6. You may not use observations made together as a class, such as during a lab.

C. Each Entry is Worth 20 pts as Follows (point values in parentheses indicate potential deductions for insufficiencies):

1. Accuracy of NatureAtlas pushpin marker placement (4 pt)
2. Taxon Block: All fields required; species, genus, and family IDs (2 pt ea), species or subspecific author (1 pt ea)
3. Location Block: Country, State, County, Municipality, Watershed, Locale Description, and Coordinates required; Park or Campus name if appropriate (1 pt ea)
4. Organism Block: All fields required; Wild status, Abundance, Life History, Sex, Description (e.g., behavioral notes, approximate size, colors and patterns on plumage, beak, eye, or legs) (1 pt ea). Of the bird(s) at that locality: not a description out of a book, etc.
5. Photograph of the organism:
   a. must be of that particular organism, not from some stock photo or a photo taken at a different time and place,
   b. must be your own photo,
   c. must be of sufficient quality for your instructor to discern the species, sex, and life history stage,
   d. must be right-side-up.

D. Fieldbook Check: Your instructor reserves the right to ask for and check through your field notebook and to deduct up to 20 points if it is not complete. Information in this notebook must match precisely the information logged into NatureAtlas.

Appendix 3. Raw data on plant taxonomy courses that were used to derive the data presented in Table 3, arranged chronologically.*

	Course (n = 20)	Collection Project	Specimen Preparation (incl. labels at minimum)	Field Notebook that Includes Sightings	Private Databasing (not available on the Web)	Public Databasing (data sharing on the Web)
2010 Sp	BIOL 4420 – Plant Taxonomy (Utah State U)	1	1	0	0	0
2010 Fa	BOT 2710 – Practical Plant Taxonomy (U of Florida)	1	1	1	0	0
2010 Fa	BIO 350 – Plant Systematics (Missouri Western State U)	1	1	0	0	0
2011 Sp	BIO 3520 – Plant Taxonomy (Cedarville U)	1	1	1	1	0
2011 Sp	BIOL 331 – Plant Taxonomy (Great Basin College)	1	0	0	0	0
2011 Sp	BIOL 348 – Plant Taxonomy (Western Kentucky U)	1	0	0	0	0
2011 Fa	BIOL 351/353 – Plant Taxonomy (Western New Mexico U)	1	1	1	0	0
2012 Fa	BOC 103 – Taxonomic Methods (Goa U, India)	1	0	1 (written report)	0	0
2012 Fa	BIO 530 – Plant Systematics (San Diego State U)	1	1	0	0	0
2012 Fa	BIO 301 – Plant Systematics (Black Hills State U)	1	1	0	0	0

(continued)

Appendix 3. Continued

	Course (n = 20)	Collection Project	Specimen Preparation (incl. labels at minimum)	Field Notebook that Includes Sightings	Private Databasing (not available on the Web)	Public Databasing (data sharing on the Web)
2012 Fa	BIOL 311 – Taxonomy of Vascular Plants (SUNY – Geneseo)	1	1	0	0	0
2013 Sp	IB 335 – Plant Taxonomy (U of Illinois)	0	0	0	0	0
2014 Sp	ESSM 304 – Rangeland Plant Taxonomy (Texas A&M U)	1	1	1	1 (file on disk)	0
2014 Sp	BIOL 366 – Plant Systematics (Iowa State U)	0	0	0	0	0
2014 Sp	BIO 4435 – Plant Taxonomy (Angelo State U)	1	0	1	1 (file on disk)	0
2014 Sp	Botany 400 – Plant Systematics (U of Wisconsin – Madison)	1	1	0	0	0
2014 Fa	BIOO 435 – Plant Systematics (Montana State U)	0	0	0	0	0
2014 Fa	BIOL 4844 – Plant Taxonomy (U of New Orleans)	1 (photos only?)	0	0	0	0
2015 Sp	BOT 5725 – Taxonomy of Vascular Plants (U of Florida)	0	0	0	0	0
2015 Su	PBIO 109 - Plant Systematics (U of Vermont)	1	1	0	0	0

*"University" is abbreviated by "U" in the list above. Semester abbreviations as follows: Sp (Spring), Fa (Fall), and Su (Summer). See Table 3 for information on how these courses were surveyed. All courses found in this survey were incidentally in the United States of America, except where indicated otherwise.

Appendix 4. Raw data on entomology courses that were used to derive the data presented in Table 3, arranged chronologically.*

	Course (n = 20)	Collection Project	Specimen Preparation (incl. labels at minimum)	Field Notebook that Includes Sightings	Private Databasing (not available on the Web)	Public Databasing (data sharing on the Web)
2011 Fa	BIOL 209 – Field Zoology (U of Vermont)	1	1	0	0	0
2011 Fa	BIOL 345 – Insect Biology (SUNY – Geneseo)	1	1	0	0	0
2011 Fa	ENTM 206/207 – General Entomology (Purdue U)	0	0	0	0	0

Appendix 4. Continued

	Course (n = 20)	Collection Project	Specimen Preparation (incl. labels at minimum)	Field Notebook that Includes Sightings	Private Databasing (not available on the Web)	Public Databasing (data sharing on the Web)
2012 Fa	CPSC 270 – Introduction to Applied Entomology (U of Illinois)	1	1	0	0	0
2012 Fa	ENT 425 – General Entomology (North Carolina State U)	1	1	0	0	0
2012 Fa	EEB 4250 – General Entomology (U of Connecticut)	1	1	0	0	0
2012 Fa	BSC 301 – Entomology (Illinois State U)	1	1	0	0	0
2012 Fa	BIOL 316 – General Entomology (Salisbury U)	1	1	0	0	0
2012 Fa	BIOL 331 – Entomology (U of North Carolina – Asheville)	1	1	0	0	0
2013 Sp	ENY 3005 – Principles of Entomology (U of Florida)	1	1	0	0	0
2013 Fa	BIOL 345 – Insect Biology (SUNY – Geneseo)	1	1	0	0	0
2013 Fa	ENTM 206/207 – General Entomology (Purdue U)	0	0	0	0	0
2014 Fa	PSSC 340 – Economic Entomology (U of California – Chico)	1	1	0	0	0
2014 Fa	ENT 425 – General Entomology (North Carolina State U)	1	1	0	0	0
2014 Fa	ENTO 3000 – Principles of Entomology (California State U)	1	1	0	0	0
2014 Fa	CPSC 270 – Introduction to Applied Entomology (U of Illinois)	1	1	0	0	0
2014 Fa	BIOL 5445 – Entomology (U of Utah)	1	1	0	0	0
2014 Fa	ENY 4004C – Entomology (U of Central Florida)	1	1	0	0	0
2014 Fa	BIOL 331 – Entomology (U of North Carolina – Asheville)	1	1	1	1 (file on disk)	0
2014 Fa	BIOL 316 – General Entomology (Salisbury U)	1	1	0	0	0

*See footnote to Table 3 and the methods description for information about how these data were compiled.

Appendix 5. Raw data on ornithology courses that were used to derive the data presented in Table 3, arranged chronologically.*

	Course (n = 20)	Collection Project	Specimen Preparation (incl. labels at minimum)	Field Notebook that Includes Sightings	Private Databasing (not available on the Web)	Public Databasing (data sharing on the Web)
2010 Sp	BIOL 4433 – Ornithology (West Texas A & M U)	0	0	0	0	0
2010 Sp	WILD 4060 – Field Ornithology (U of Georgia)	0	0	0	0	0
2011 Sp	IB 461 – Ornithology (U of Illinois)	0	0	1	0	0
2011 Sp	WFB 130 – Ornithology (U of Vermont)	0	0	1	0	0
2011 Sp	Ornithology 11:704:323 (Rutgers U)	0	0	0	0	0
2012 Sp	BIO 4734 – Ornithology (U of Central Oklahoma)	0	0	0	0	0
2012 Fa	BIOL 4900 – Ornithology (Dalton State U)	0	0	0	0	0
2013 Sp	EBIO 4200 – Ornithology (Tulane U)	0	0	1	0	0
2013 Sp	BI 347 – Ornithology (Saint Anselm College)	0	0	0	0	0
2013 Sp	BIOL 4425 – Ornithology (Texas A & M U – Kingsville)	0	0	1	0	0
2014 Sp	BIOL 4425 – Ornithology (Texas A&M U)	0	0	0	0	0
2014 Sp	IB 461 – Ornithology (U of Illinois – Urbana-Champaign)	0	0	1	0	0
2014 Sp	BI 200 – Ornithology (Central Methodist U)	0	0	0	0	0
2014 Sp	Biology 328 – Ornithology (U of Wisconsin – Oshkosh)	0	0	0	0	0
2014 Su	BIOSM 3740 – Field Ornithology (Shoals Marine Laboratory)	0	0	1	0	0
2015 Sp	ZOOL 4408 – Ornithology (Texas Tech U)	0	0	0	0	0
2015 Sp	ZOOL 435 – Ornithology (California State Polytechnic U)	0	0	0	0	0
2015 Sp	BIOL 379 – Ornithology (U of Puget Sound)	0	0	1	0	0

Appendix 5. Continued

	Course (n = 20)	Collection Project	Specimen Preparation (incl. labels at minimum)	Field Notebook that Includes Sightings	Private Databasing (not available on the Web)	Public Databasing (data sharing on the Web)
2015 Sp	BIOL 4056 – Ornithology (U of North Texas)	0	0	1 (copy of eBird report)	0	1 (eBird)
2015 Su	BIOL 3268 – Marine Ornithology (Dalhousie U)	0	0	1	0	0

*See footnote to Table 3 and the methods description for information about how these data were compiled.

Appendix 6. Results of the locality verification study (continued on next page). This subset of the Spring 2010 and Fall 2010 semester collections consists of the 64 woody plants collected in the Millersville University Biological Preserve on the Millersville University campus. We were able to locate the reported species within a 25 m radius of the non-random locations (i.e., the actual reported latitude and longitude) in 60 of 64 instances. When these same records were assigned to random locations within the Preserve, we were able to find the respective species in only 42 of 64 cases. All collections were deposited in the James C. Parks Herbarium and are ordered here by the last name of the collector followed by his or her collection number for the specimen.

Record by Voucher ID in Herbarium	Species	Latitude (WGS 84 decimal)	Longitude (WGS 84 decimal)	Non-random Find?	Random Find?
Akhmedov 3	*Lindera benzoin*	39.99818586	−76.34565711	yes	yes
Akhmedov 9	*Cercis canadensis*	39.99704958	−76.34531111	yes	no
Apaliski 2	*Cercis canadensis*	39.99703759	−76.34528562	yes	no
Apaliski 4	*Rosa multiflora*	39.99737423	−76.34591997	yes	yes
Apaliski 5	*Lonicera japonica*	39.99771532	−76.34591728	yes	yes
Apaliski s.n.	*Acer negundo*	39.99737629	−76.34596556	yes	yes
Baluyan 6	*Pyrus calleryana*	39.99912556	−76.34551764	yes	no
Bet 10	*Hedera helix*	39.99639472	−76.3471055	yes	no
Bet 3	*Cercis canadensis*	39.99725773	−76.34519041	yes	no
Bet 8	*Liriodendron tulipifera*	39.9970954	−76.34712964	yes	yes
Bet 9	*Acer platanoides*	39.99664335	−76.34701431	yes	yes
Buchanan 10	*Acer negundo*	39.99488175	−76.34567857	yes	yes
Buchanan 9	*Berberis thunbergii*	39.99322963	−76.34529233	yes	yes
Cass 9	*Berberis thunbergii*	39.99253782	−76.34460032	no	yes
Chappelle 7	*Euonymus alatus*	39.9947749	−76.34577513	yes	yes

(continued)

Appendix 6. Continued

Record by Voucher ID in Herbarium	Species	Latitude (WGS 84 decimal)	Longitude (WGS 84 decimal)	Non-random Find?	Random Find?
Ciafre 3	*Asimina triloba*	39.99542286	−76.34702235	yes	yes
Dommel 1	*Lindera benzoin*	39.99531875	−76.34741127	yes	no
Dommel 10	*Euonymus alatus*	39.99646807	−76.34661198	yes	no
Driedger 1	*Malus pumila*	39.99662424	−76.34706259	yes	no
Driedger 10	*Asimina triloba*	39.99568314	−76.34682655	yes	yes
Dull 2	*Asimina triloba*	39.99546532	−76.34719133	yes	yes
Dyer 12	*Asimina triloba*	39.99246658	−76.34506702	yes	no
Dyer 6	*Asimina triloba*	39.99454886	−76.34616941	yes	yes
Gibiser 1	*Lonicera japonica*	39.99529272	−76.34856462	yes	yes
Grab 4	*Rosa multiflora*	39.99615821	−76.34720206	yes	yes
Grab 5	*Lindera benzoin*	39.99575547	−76.34616137	yes	yes
Grab 7	*Euonymus alatus*	39.99488422	−76.34646177	yes	yes
Hartlove 14	*Acer negundo*	39.9944242	−76.34808451	yes	yes
Hartlove 16	*Viburnum cassinoides*	39.99434749	−76.347363	yes	yes
Hartlove 17	*Rosa multiflora*	39.99431941	−76.34744078	yes	yes
Hartlove 5	*Asimina triloba*	39.9936002	−76.34606749	yes	yes
Hughes 10	*Rosa multiflora*	39.99880023	−76.34480417	yes	yes
Kikola 14	*Euonymus alatus*	39.99852969	−76.34471029	yes	no
Kikola 7	*Rosa multiflora*	39.99376048	−76.34660393	yes	no
Lehr 10	*Lindera benzoin*	39.99449393	−76.34586632	yes	yes
Lehr 2	*Asimina triloba*	39.99550916	−76.34713769	yes	no
Madera 10	*Cercis canadensis*	39.99664889	−76.34551227	yes	no
Nekula 4	*Acer platanoides*	39.99642903	−76.34619087	yes	no
Packer, C. 14	*Lonicera japonica*	39.99517902	−76.34841442	yes	yes
Packer, C. 18	*Euonymus alatus*	39.99526943	−76.34838223	no	yes
Packer, C. 3	*Rhodotypos scandens*	39.99488312	−76.34747565	yes	no
Packer, D. 3	*Euonymus alatus*	39.99382966	−76.3459146	yes	no
Packer, D. 4	*Rhodotypos scandens*	39.99477079	−76.34782702	yes	no
Raczka 2	*Asimina triloba*	39.99228616	−76.34464109	yes	yes
Ross 2	*Lindera benzoin*	39.99696396	−76.3452065	yes	yes
Schmidt 11	*Rosa multiflora*	39.99733108	−76.34638935	yes	yes
Schmidt 3	*Lindera benzoin*	39.99620571	−76.34621233	yes	yes

Appendix 6. Continued

Record by Voucher ID in Herbarium	Species	Latitude (WGS 84 decimal)	Longitude (WGS 84 decimal)	Non-random Find?	Random Find?
Shirk 8	*Euonymus alatus*	39.99431461	−76.34678364	yes	yes
Shirk 9	*Lonicera japonica*	39.99458722	−76.34698749	yes	yes
Sierra 2	*Euonymus alatus*	39.99546	−76.347169	yes	yes
Sloyer 3	*Lindera benzoin*	39.99590095	−76.34672999	yes	yes
Sloyer 8	*Euonymus alatus*	39.9952845	−76.34612918	yes	yes
Stabley 4	*Asimina triloba*	39.99562149	−76.34577513	yes	yes
Startzel 1	*Rosa multiflora*	39.99714684	−76.34634376	yes	yes
Startzel 6	*Euonymus alatus*	39.99573519	−76.34708673	no	no
Stiber 4	*Euonymus alatus*	39.99517559	−76.34573758	yes	yes
Tangert 9	*Rosa multiflora*	39.99429201	−76.347422	yes	yes
Vargas 3	*Elaeagnus angustifolia*	39.99671465	−76.34652615	yes	no
Vargas 4	*Toxicodendron radicans*	39.99668794	−76.34670317	yes	yes
Wallen 4	*Euonymus fortunei*	39.994916	−76.34715378	no	no
Wallen 6	*Hedera helix*	39.99408173	−76.34598434	yes	no
Wright 3	*Rosa multiflora*	39.99405837	−76.34677559	yes	yes
Wright 4	*Euonymus alatus*	39.99427002	−76.34672731	yes	no
Wright 5	*Lonicera japonica*	39.99458852	−76.34696335	yes	no