Repeated Monitoring of Forest Plots: Evaluating the Accuracy of Student Scientist Data[1,2]

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Abstract

The accuracy of vegetation data collected from permanent forest plots by Virginia and Georgia high school citizen scientists was compared against an expert-developed answer key. Several factors appear to influence citizen scientist data collection accuracy, including education of trainers, biodiversity of vegetation plots, whether students enrolled in an elective or required science course and plot preparation. When university faculty provided training for the high school students during data collection, they achieved 96% accuracy on measuring tree diameters. When undergraduate students provided the training, the accuracy of tree diameter measurements declined to 75%. A forest's species diversity also influenced data accuracy, with students who measured the more-diverse forest in Georgia being able to identify 80% of the trees correctly, while students working in the less-diverse Virginia forest were able to identify 97% of the species correctly. High school students enrolled in elective agriculture or environmental science classes measured tree diameters more accurately (78% accuracy) than students who were enrolled in mandatory science classes (69% accuracy). The accuracy of data collected by high school citizen scientists increased in plots where researchers placed metal tags on all trees that needed to be sampled (6% error rate), rather than having students establish the plot dimensions with measuring tapes and determine for themselves what trees were in or out of their sampling plot (95% error rate).

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Introduction

Citizen science programs provide hands-on learning opportunities to engage students in all aspects of science. Through these programs, students can learn about ecosystems, biodiversity and wildlife-habitat relationships all while participating in the active collection of data to address scientific research objectives (Bonney et al., 2009). Citizen scientist programs have the dual goals of contributing to the advancement of scientific knowledge while expanding scientific literacy. When these programs specifically target youth they increase the awareness and appeal of science as a career option (Jenkins, 2011). For students, citizen science programs link classroom content with everyday life by moving scientific material from a theoretical to a tangible form and allow students to be active learners. Science educators find citizen scientist programs valuable for high school students who do not respond well to traditional teaching methods because these experiences provide diversity in the physical and intellectual learning environment (Jenkins, 2011).

High school students who participate in citizen scientist programs tend to fit into two groups: students participating as part of a school-based project or students participating under the guidance of a parent or other adult (Galloway et al., 2006; Delaney et al., 2008; Weckel et al., 2010). School-centered programs can be incorporated into class projects that rely on traditional grading systems or teachers can encourage students to participate in programs that occur outside of normal classroom-based activities through small gift incentives (Galloway et al., 2011). Students who participate in non-school based citizen scientist programs often work under the guidance of adults through organizations such as 4-H, FFA, Boy or Girl Scouts of America, or with local parks or wildlife refuges.

One common concern with data collected by citizen scientists, especially when working with student citizen scientists, is whether the data collected by volunteers are accurate. When assessing "accuracy" of data the use of a reference point of the existing conditions is important. Some studies professing to assess the accuracy of citizen scientist data have instead assessed the reliability of the data. In this sense, reliability is how similar data collected by two groups are to each other. For example, data collected by citizen scientists were compared to data collected by other citizen scientists from the same site or to data collected in similar studies in the same region to determine reliability (Weckel et al., 2010; Jordan et al., 2012). Selecting an appropriate reference point for assessing the accuracy of data collected by citizen scientists is difficult. However, the root of the question is whether the data collected by citizen scientists is less accurate than what would have been collected by trained scientists; therefore, comparing citizens' data to data collected by professional scientific researchers appears to be the best approach (Gillett et al., 2012; Jordan et al., 2012). To accomplish this, one assessment approach is to have synchronous data collection, in which both citizen scientists and professionals collect data at the same time and location and then compare the results (Delaney et al., 2008; Galloway et al., 2011). An alternative approach is to have research professionals collect the data in advance and then compare the citizen scientist data with the professional standard or benchmark (Crall et al., 2010).

The objective of this study was to assess the accuracy of high school student collected data from projects that involve re-sampling permanent forest plots. Three research questions guided the study:

1. How accurately can high school students collect tree diameter data (compared to an established answer key)?
2. How accurately can high school students identify trees within fixed area plots with the aid of a site specific dichotomous key?
3. Is data collection accuracy influenced by the scientific background of the adult instructor in high school citizen scientist programs?

For the current study, high school environmental science/earth science students completed five sampling periods at Mason Neck National Wildlife Refuge in northeastern Virginia (N 38°40'38", W 77°15'52") as part of their science coursework and high school agriculture students completed two sampling periods at Indian Springs State Park in central Georgia (N 33°14'50", W 83°55'19"). At both of these study areas, prior data were collected by researchers from Virginia Tech and the University of Georgia to provide a baseline (answer key) for comparing the accuracy of the student collected data. The students collected the data during a full-day field trip that was a part of their normal school curriculum.

Materials and Methods

Study Areas and Partnerships

Partnerships were established with teachers and high schools in Virginia and Georgia, which resulted in seven outdoor citizen scientist field trips during three consecutive years (Table 1). However, these sessions should not be viewed as replications because the experience was an iterative process in which revisions were made to the teaching approaches each time in an attempt to improve the educational experience and the quality of data collected by the students. Prior to student data collection, we established permanent plots (0.02 ha) with a wooden stake marking the plot center for a plot with a radius of 8 m. Species and diameter of all trees exceeding 10 cm diameter at breast height (DBH, 1.4 m) were carefully measured and recorded by experienced university researchers. We developed a project-based website for both the Virginia (http://dendro.cnre.vt.edu/mason/) and Georgia (http://dendro.cnre.vt.edu/indiansprings/) field sites to prepare students for their experience prior to leaving the classroom. The website included environmental and historical information about the field site, identified the research objectives, described

Table 1. Summary of the seven citizen scientist experiences. High school citizen scientists came from environmental science and earth science classes at Freedom High School (FHS) and Patriot High School (PHS) in Virginia and agriculture students at Locust Grove High School (LGHS) in Georgia.

Teaching Sessions[w]	Educational Site[y]	High School	Instructors[z]
1	MNNWR	FHS	VT faculty
2	MNNWR	FHS	FHS teachers
3[x]	MNNWR	FHS	VT faculty, grad students, FHS teachers
4[x]	ISSP	LGHS	VT forestry undergrad students
5[x]	MNNWR	FHS	VT forestry undergrad students
6[x]	ISSP	LGHS	VT forestry & UGA agricultural communications undergrad students
7[x]	MNNWR	PHS	VT forestry & UGA agricultural communications undergrad students

[w] Teaching sessions were held between 2008 and 2011.

[x] Numbered tree tags placed at breast height on all trees within permanent sampling plot and group leaders were provided answer keys.

[y] MNNWR - Mason Neck National Wildlife Refuge (N 38°40'38", W 77°15'52") and ISSP - Indian Springs State Park (N 33°14'50", W 83°55'19").

[z] Instructors included faculty, graduate students, and undergraduates from Virginia Tech (VT) and University of Georgia (UGA) and high school teachers from Freedom High School (FHS).

the field methods, had site-specific tree keys and hosted an electronic data entry form where the students would enter collected data, under the supervision of the high school teacher. Prior to each citizen scientist session, university faculty met with high school science teachers for a half-day training. Training involved classroom work to familiarize the teachers with the project's objectives and website. The training also included an outdoor practicum at the field site to demonstrate the sampling techniques students would use and reduce any anxiety of the teachers.

During the citizen scientist sessions, high school students sampled the permanent vegetation plots and recorded tree species and DBH at both sites. Five of the seven sessions were located at Mason Neck National Wildlife Refuge in Virginia with four involving high school students from Freedom High School (an environmental science magnet school) and one with students from Patriot High School. Two of the citizen scientist sessions were located at Indian Springs State Park and involved high school students from Locust Grove High School in Georgia.

The first data collection occurred at Mason Neck National Wildlife Refuge in the fall of 2008 and partnered high school students from three different classes at Freedom High School with faculty from Virginia Tech (Table 1). The faculty taught the high school students how to use different sampling tools and led the students through the sampling of the permanent vegetation plots. The high school students then returned to their classrooms to enter the data into the project website.

The second citizen scientist data collection session occurred at Mason Neck National Wildlife Refuge in the spring of 2009 and was different because it involved Freedom High School teachers leading a different group of students through the same vegetation sampling experience, without participation of the university faculty. Again, high school students entered data into the website to allow a comparison of the accuracy with the baseline dataset.

For the third citizen scientist data collection session (fall 2009, Table 1), we attempted to reduce errors students had demonstrated in earlier sessions related to deciding whether to include or exclude trees that were located along the perimeter of the permanent plot by adding numbered tree tags to all trees within the plots. We also provided each of the adult leaders with an answer key for reference while collecting data with the students. University faculty, graduate students and high school teachers led the data collection for this third session. After collection, high school students entered their data into the website for comparison with the baseline dataset.

For our fourth citizen scientist session in the fall of 2010, we attempted to decrease the age gap between instructors and high school students by having undergraduates from Virginia Tech teach high school students from Locust Grove High School in Georgia at Indian Springs State Park (Table 1). Again, high school students entered their data into the website to allow us to compare the accuracy of their data to the answer key.

For the fifth citizen scientist session also in the fall of 2010, the same undergraduates from Virginia Tech who had taught at Indian Springs State Park led high school students from Freedom High School in Virginia at Mason Neck National Wildlife Refuge in the collection of data from the permanent plots. Thus, the undergraduates were provided the opportunity to improve their teaching approach based on their earlier experience in Georgia. High school students again entered their data into the website for accuracy assessment.

For the sixth citizen scientist session, Virginia Tech and University of Georgia undergraduates team-taught Georgia high school students from Locust Grove High School at Indian Springs State Park (fall 2011, Table 1). The Virginia Tech and University of Georgia undergraduates had worked together to improve their team-teaching skills and leadership skills at a weekend workshop prior to the teaching day. After data collection, high school students returned to their classrooms to enter their data into the website.

The seventh and final citizen scientist session was team-taught by a different group of undergraduates from Virginia Tech and the University of Georgia and had Virginia high school students from Patriot High School sampling the permanent plots at Mason Neck National Wildlife Refuge in the fall of 2011 (Table 1). This group of Virginia Tech and University of Georgia undergraduate students has also participated in the weekend teaching and leadership workshop. Again, high school students entered their collected data on the website.

Data analysis

Accuracy of Tree Diameter (DBH) Data

We examined the accuracy of student collected tree diameter data by comparing student measurements to an answer key established by trained university faculty at each location. Accuracy was then defined in two ways: (1) by determining if student collected DBH data were within +/- 0.25 cm (1/10 inch) of the answer key - the standard used by the U.S. Forest Service in their Forest Inventory and Analysis program (Woudenberg et al., 2010) and (2) by determining if student collected DBH data were within +/- 0.75 cm (3/10 inch) of the answer key (a standard created by the researchers). Accuracy values were compared across the seven teaching sessions, by student type (environmental/earth science high school students vs. agricultural education high school students) and by instructor type (university faculty, high school teachers, or undergraduate students). Frequencies and percentages were used to summarize the data by reporting how often DBH measurements collected by high school students matched the answer key within +/- 0.25 cm (U.S. Forest Service Standard) and within +/- 0.75 cm (Researcher Standard).

Accuracy of Tree Species Data

During all citizen scientist sessions, high school students identified tree species within sampling plots using a site specific dichotomous key that included photographs of buds, leaves and bark. Accuracy of student identification of tree species was examined by comparing student responses to tree species data on a site specific answer key established by trained university faculty at each location. We coded student responses as correct, incorrect, or semi-correct. Semi-correct answers were tagged when the students identified the correct genus, but incorrectly identified the species e.g., a red maple (*Acer rubrum*) identified as a sugar maple (*Acer saccharum*). Accuracy values were again compared across the seven teaching sessions, by student type and by instructor type. Frequencies and percentages were used to summarize the data by reporting how often high school students identified tree species within a plot as correctly, semi-correctly, or incorrectly.

Results

Accuracy of Tree Diameter (DBH) Data

Regardless of the standard for tree diameter comparison, students were most accurate when instructed by trained university faculty (session 1, see Table 2). Data tended to be less accurate when students were instructed by graduate students or undergraduate students (sessions 3-7). At Mason Neck National Wildlife Refuge, tree diameter data were less accurate when collected by students who were instructed by their high school science teachers when compared to university faculty and more accurate when compared to undergraduate students. However, teachers had been trained on appropriate field data collection techniques prior to assisting their students with data collection. At Indian Springs State Park, tree diameter data were most accurate when collected by high school students who were instructed by teams of undergraduate students comprised of forestry students (Virginia Tech) and agricultural communications students (University of Georgia, Table 2). However, tree diameter data were least accurate when collected by high school students who were instructed solely by forestry undergraduate students.

We compared the accuracy of the tree diameter data across the types of high school classes that collected the data. High school students from agricultural education classes collected data that was very similar in accuracy to data collected by students from environmental/earth science classes (Table 3). There were a total of two sessions that included agricultural education classes (all from Indian Springs State Park) and five sessions of environmental/earth science classes (all from Mason Neck National Wildlife Refuge); therefore, the averages represent different numbers of sessions.

Accuracy of Tree Species Data

The ability of high school students to accurately identify tree species within fixed plots was also examined across data collection sessions. We summarized accuracy of tree species data into three categories: correctly identified trees, incorrectly identified trees and semi-correctly identified trees. On average, high school students collecting data at Mason Neck National Wildlife Refuge were accurate (completely correct) with tree identification 97% of the time, regardless of the teaching session (Table 4). However, high school students collecting data at Indian Springs State Park were, on average, accurate with tree identification 80% of the time. A higher proportion of trees were identified incorrectly or semi-cor-

Table 2. Accuracy of tree diameter data collected by high school students from Virginia and Georgia during seven citizen scientist experiences held between 2008 and 2011. Details of the format for each session are provided in Table 1.

Teaching Session	Accuracy Compared to Forest Service Standard (+- 0.25cm)	Accuracy Compared to Researcher Standard (+-0.75cm)
1	83.6%	96.4%
2	81.3%	81.3%
3[z]	28.1%	75.0%
4[z]	44.0%	78.7%
5[z]	19.5%	65.5%
6[z]	78.7%	81.3%
7[z]	32.0%	72.0%

[z] Numbered tree tags placed at breast height on all trees within permanent sampling plot and group leaders were provided answer keys.

Table 3. Accuracy of tree diameter data measured by high school students from Virginia and Georgia during citizen scientist sessions held between 2008 and 2011 based on the type of high school class. Details of the format for each session are provided in Table 1.

Type of High School Class	Accuracy Compared to Forest Service Standard (+-.25cm)	Accuracy Compared to Researcher Standard (+-.75cm)
Environmental/Earth Science	38.6%	76.2%
Agriculture	40.7%	79.1%

Table 4. Accuracy of tree species data collected by high school students from Virginia and Georgia during seven citizen scientist teaching sessions from 2008 to 2011. Semi-correct values represent a correct identification of the genus but an incorrect identification of the species.

Teaching Session[x]	Completely Correct	Semi-correct	Incorrect
MNNWR[y]			
1	95.9%	3.1%	1.0%
2	93.3%	6.7%	0%
3[z]	97.6%	1.6%	0.8%
5[z]	99.0%	0%	1.0%
7[z]	100%	0%	0%
Average	97.2%	2.3%	0.6%
ISSP[y]			
4[z]	84.2%	14.5%	1.3%
6[z]	75.0%	12.5%	12.5%
Average	79.6%	13.5%	6.9%

[x] Details on the format of each session are provided in Table 1.

[y] MNNWR - Mason Neck National Wildlife Refuge and ISSP - Indian Springs State Park.

[z] Numbered tree tags placed at breast height on all trees within permanent sampling plot and group leaders were provided answer keys.

Table 5. Amount of error in data collected by high school students from Virginia and Georgia during seven citizen scientists experiences held from 2008 to 2011. Details of the format for each session are provided in Table 1.

Teaching Session	Number of Errors	Number of Trees in Plots	Percent Error
Student data collected before tree tags installed	97	102	95%
Student data collected after tree tags installed	14	241	6%

rectly at Indian Springs State Park than at Mason Neck National Wildlife Refuge (Table 4).

Influence of Tree Tags on Data Accuracy

For the first two data collection sessions (Table 1), high school students were provided with a plot center, but had to measure the 8 m radius of the circular plots with a tape measure and determine which trees were “in” or “out” of the plot boundaries. The error rate on either excluding trees they should have included or including trees they should have excluded was very high (95% error rate). This high error rate prompted us to attempt to reduce this error, so we nailed numbered, metal tree tags at breast height on all trees that should be included within each plot. Students in the subsequent data collection sessions averaged only a 6% error rate and made substantially fewer inclusion/exclusion mistakes (Table 5). In contrast to the improvement in inclusion/exclusion mistakes, the accuracy of the DBH measurements declined after the addition of tree tags (Table 2). This decline in accuracy may be due to other factors, such as adult leaders in subsequent data collections sessions (undergraduate students) having less experience than either university faculty or trained science teachers.

Discussion

Accuracy of Tree Diameter Data Collected by Agriculture vs. Environmental Science Students

Students who enroll in agriculture classes as part of their high school curriculum benefit from this experience through higher scores on standardized science tests, more supportive attitudes towards agriculture and lower drop-out rates (Bishop, 1989; Dyer et al., 1996; Chiasson and Burnett, 2001). However, students enrolled in agriculture classes (79% accuracy on diameter measurements) did not collect substantially more accurate data compared to their counterparts who were enrolled in environmental/earth science classes, but had not taken agriculture classes during their high school program (76% accuracy on diameter measurements, Table 3). The benefits of the additional agriculture classes may not appear as an improvement in data accuracy because the high school students from Sessions 1-3 were enrolled in an elective environmental science class and therefore chose to be in that course. The benefits garnered for students from taking additional science classes have been well documented (Levine and Zimmerman, 1995). The least accurate diameter data were collected during Sessions 5 and 7 by high school citizen scientists who were enrolled in a mandatory science class (Table 2). Perhaps students who are interested in science and enroll in elective science courses take these field experiences more seriously, record data more accurately and enter their data online more carefully than students in mandatory science courses.

Tree Identification Data Accuracy Across Study Sites

Generally, plant species richness (number of species) increases with closer proximity to the equator and Mason Neck National Wildlife Refuge in northern Virginia (species richness 12) and Indian Springs State Park in central Georgia (species richness = 16) followed this pattern. At Mason Neck National Wildlife Refuge students achieved 97% accuracy in their tree identification (Table 4), while at the more diverse Indian Springs State Park high school students were only able to identify 80% of the trees correctly (Table 4). Another challenge for the students at Indian Springs State Park and one that resulted in a high number of semi-correct tree identifications (correct genus, but wrong species identification), was the high number of oak (*Quercus*) species present. Mason Neck National Wildlife Refuge had two oak species: white oak (Quercus alba) and southern red oak (*Quercus falcata*). In contrast, Indian Springs State Park had six oak species: white oak, southern red oak, water oak (*Quercus nigra*), northern red oak (*Quercus rubra*), post oak (*Quercus stellata*) and black oak (*Quercus velutina*). Identifying plants to the species level is more challenging than identifying plants to the genus level. Among professional plant scientists, 75% of mistakes in plant identification accurately identified the genus, but misidentified species (Luczaj, 2010). Thus, based on the results from this study (Table 4), citizen scientist programs based in regions with high biodiversity are likely to have more errors in species identifications than regions with lower biodiversity. This issue is of particular concern for high-diversity tropical regions that rely upon citizen scientists to collect data and monitor ecosystem changes. Invasive species citizen scientist programs have addressed this challenge by having volunteers collect data for a single taxon (Crall et al., 2010), a practice that greatly reduces training time for new citizen scientists.

Influence of the Scientific Background of the Adult Instructor

Introductory training for citizen scientists is important in any citizen scientist program. Most programs provide interactive training sessions led by professional researchers, where citizen scientists practice new skills for data collection. After training, citizen scientists collect data independently (Gardiner et al., 2012; Gollan et al., 2012). The seven citizen scientist sessions in this study involved high school students rather than adults; therefore, the students collected data under the supervision of an adult citizen scientist instructor (Table 1). The educational background of the instructor varied across the sessions, thus, providing an interesting comparison of how their education level influenced the accuracy of citizen scientist data collection. The high school students collected the most accurate data when they worked in teams coordinated by university faculty (session 1, 96% accuracy on diameter measurements, Table 2) and the least accurate data were collected when high school students were instructed by undergraduate students (sessions 4-5 and 7, 75% accuracy on diameter measurements, Table 2). However, our intention in placing undergraduates in the position of team instructors was to increase high school student's career awareness of natural resources and agriculture by providing them with a role model who was closer to their own age and thus more likely to share common interests (Schmidt et al., 2004). In fact, at Indian Springs State Park, the most accurate data were collected by high student students instructed by teams of forestry and agricultural communications undergraduate students (Table 2). The skill sets of the two majors seem to complement each other, with forestry undergraduates bringing content knowledge and agricultural communication undergraduates bringing the teaching methods expertise. Given the success of citizen scientist programs at providing urban high school students with an opportunity to visualize themselves in a career pathway with which they otherwise would have had no exposure (Bombaugh, 2000), lower accuracy may be an acceptable trade-off in disciplines where recruiting students is a challenge.

Recommendations for Future Citizen Scientist Programs

This study indicates four main approaches to improve the accuracy of scientific data collected by citizen scientist programs. First, citizen scientists should be trained by experienced researchers. Second, when planning the infrastructure for repeat measurements provide on-site demarcations to indicate what should be sampled by the citizen scientists, e.g., for forest sampling use permanent plot centers, tree tags and mark the level of breast height on all trees. Third, when possible, limit citizen scientist programs to regions with lower biodiversity. If the region of interest is an area of high natural biodiversity, limit citizen scientist measurements to a single species. Finally, for volunteer-based citizen scientist programs, recruit individuals who have taken agricultural or science classes as part of their high school education.

Literature Cited

Bishop, J. 1989. Occupational training in high school: when does it pay off? Economics of Education Review 8(1):1-15.

Bombaugh, R. 2000. From citizen scientists to engineers. Journal of Professional Issues in Engineering Education and Practice 126(2):64-68.

Bonney, R., C.B. Cooper, J. Dickinson, S. Kelling, T. Phillips, K.V. Rosenberg and J. Shirk. 2009. Citizen scientist: a developing tool for expanding science knowledge and scientific learning. Bioscience 59(11):977-984.

Chiasson, T.C. and M.F. Burnett. 2001. The influence of enrollment in agrisciences courses on the science of achievement of high school students. Journal of Agricultural Education 42(1):61-71.

Crall, A.W., G.J. Newman, C.S. Jarnevich, T.J. Stohlgren, D.M. Waller and J. Graham. 2010. Improving and integrating data on invasive species collected by citizen scientists. Biological Invasions 12(10):3419-3428.

Delaney, D.G., C.D. Sperling, C.S. Adams and B. Leung. 2008. Marine invasive species: validation of citizen science and implications for national monitoring networks. Biological Invasions 10(1):117-128.

Dyer, J.E., R. Lacey and E.W. Osborne. 1996. Attitudes of University of Illinois College of Agriculture freshmen toward agriculture. Journal of Agricultural Education 37(3):33-42.

Galloway, A., R. Hickey and G. Koehler. 2011. A survey of ungulates by students along rural school bus routes. Society and Natural Resources 24(2):201-204.

Galloway, A.W.E., M.T. Tudor and W.M. VanderHaegen. 2006. The reliability of citizen science: a case study of Oregon white oak stand surveys. Wildlife Society Bulletin 34(5):1425-1429.

Gardiner, M.M., L.L. Allee, P.M.J. Brown, J.E. Losey, H.E. Roy and R.R. Smyth. 2012. Lessons from lady beetles: accuracy of monitoring data from US and UK citizen-scientist programs. Frontiers in Ecology and Environment 10(9):471-476.

Gillett, D.J., D.J. Pondella, J. Freiwald, K.C. Schiff, J.E. Caselle, C. Shuman and S.B. Weisberg. 2012. Comparing volunteer and professionally collected monitoring data from the rocky subtidal reefs of southern California, USA. Environmental Monitoring and Assessment 184:3239-3257.

Gollan, J., L.L. deBruyn, N. Reid and L. Wilkie. 2012. Can volunteers collect data that are comparable to professional scientists? A study of variables used in monitoring the outcomes of ecosystem rehabilitation. Environmental Management 50(5):969-978.

Jenkins, L.L. 2011. Using citizen science beyond teaching science content: a strategy for making science relevant to student's lives. Cultural Studies of Science Education 6(2):501-508.

Jordan, R.C., W.R. Brooks, D.V. Howe and J.G. Ehrenfeld. 2012. Evaluating the performance of volunteers in mapping invasive plants in public conservation lands. Environmental Management 49(2):425-434.

Levine, P.B. and D.J. Zimmerman. 1995. The benefit of additional high-school math and science classes for young men and women. Journal of Business and Economic Statistics 13(2):137-149.

Luczaj, L.J. 2010. Plant identification credibility in ethnobotany: a closer look at Polish ethnographic studies. Journal of Ethnobiology and Ethnomedicine 6:36.

Schmidt, M.E., J.L. Marks and L. Derrico. 2004. What a difference mentoring makes: service learning and engagement for college students. Mentoring & Tutoring: Partnership in Learning 12(2):205-217.

Weckel, M.E., D. Mack, C. Nagy, R. Christie and A. Wincorn. 2010. Using citizen science to map human-coyote interaction in suburban New York, USA. Journal of Wildlife Management 74(5):1163-1171.

Woudenberg, S.W., B.L. Conkling, B.M. O'Connell, E.B. LaPoint, J.A. Turner and K.L. Waddell. 2010. The Forest Inventory and Analysis Database: database description and users manual version 4.0 for Phase 2. General Technical Report RMRS-GTR-245. USDA Forest Service Rocky Mountain Research Station, Fort Collins, CO.