Permanent Forestry Plots: A Potentially Valuable Teaching Resource in Undergraduate Biology Programs for the Caribbean

Henri Vallès[1,*] and C.M. Sean Carrington[1]

Abstract - There has been a recent proposal to change the way that biology is taught and learned in undergraduate biology programs in the USA so that students develop a better understanding of science and the natural world. Here, we use this new, recommended teaching–learning framework to assert that permanent forestry plots could be a valuable tool to help develop biology literacy in the Caribbean and to help reverse what we perceive to be a trend of increasing detachment from nature in our Caribbean undergraduate biology students.

Introduction

In a recent report on how to teach biology entitled Vision and Change, the American Association for the Advancement of Science (AAAS) outlined several core concepts and competencies that biology undergraduate students in the USA should be exposed to and acquire, respectively, to enhance their comprehension of biological sciences (AAAS 2009). Importantly, the AAAS (2009) emphasized that the degree to which learning outcomes were likely to be achieved in biology would depend on the ability to: (1) relate abstract concepts to real-world situations that are relevant to the student, (2) engage students as active participants of the teaching–learning process, rather than as passive recipients of information, (3) ensure that the acquisition of knowledge is outcome-oriented and inquiry-driven, and (4) ensure that an active research experience is part of the teaching–learning process. The AAAS revision was motivated by a perceived decline in science and technology comprehension, workforce capabilities, and US national competitiveness among science undergraduates.

We believe that the same principles should apply to the teaching of biology, and science in general, in our insular Caribbean undergraduate context. We assert that applying these principles to biology instruction is also critical to helping foster a long-lasting appreciation of the value of biodiversity and ecosystem services among our Caribbean undergraduate biology students, i.e., if you know about it, you are more likely to care about it. Indeed, there is evidence that as societies become urbanized and technology-savvy across the globe, citizens also become less willing or able to experience nature (Pergams and Zaradic 2008), potentially resulting in increasingly nature-detached societies (Kareiva 2008). The Caribbean region is likely not an exception to this trend. In our specific teaching–learning

[1]Department of Biological and Chemical Sciences, The University of the West Indies, Cave Hill Campus, Barbados. [*]Corresponding author - henri.valles@cavehill.uwi.edu.

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environment, we have noted this disconnect among our undergraduate biology students. They generally have almost no knowledge of the plants and animals around them; most cannot even recognize a common tree such as *Swietenia mahagoni* (L.) Jacq. (West Indies Mahogany). Many students have never had a wildlife experience (e.g., been in a forested area or snorkled on a coral reef) even though opportunities to do so are within reach, and for some students the anticipation of such experience automatically draws feelings of aversion (see also Bixler and Floyd 1997). Our experience includes anecdotes of students showing up for strenuous field trips into densely forested gullies wearing beach sandals. The detachment from nature we have observed is worrisome because the environmental policies of tomorrow will be made by this young generation. In the face of climate change, this situation casts a gloomy shadow over the future of the unique biodiversity of the insular Caribbean, currently threatened by habitat loss (Myers et al. 2000), and over the sustainability of the ecosystem services and products that people in Caribbean islands currently rely upon (Mimura et al. 2007). The lack of students' connection to the natural world also suggests that the natural heritage component of Caribbean culture will decline further as our interaction with the plants and animals around us becomes less and less significant in our daily lives.

In addition to the fact that it is crucial to establish long-term permanent forestry plots (PFPs) so that we can obtain data on patterns and rates of change in forested systems (Acker et al. 1998), we think PFPs could also play a significant role as teaching–learning tools to both improve the teaching of biology and help reverse the trend toward alienation from nature that we have noted in many of our biology students. In this communication, we briefly highlight how PFPs could contribute toward the development of some of the biological core concepts and competencies outlined in the AAAS 2009 report while helping restore some of those lost links between undergraduate biology students and nature.

PFPs and Core Concepts and Competencies in Biology

According to the AAAS (2009), biology literacy should be defined mainly as a function of acquired competencies, demonstrated within the context of key biological concepts (Table 1). In our Caribbean context, we think that vascular plant communities in forested areas offer a tractable, low-cost study-system with conspicuous, easily recognizable, and easily measurable components for which supplemental data can be readily obtained from a diverse range of sources. Importantly, for at least small Caribbean island states, such study-systems are very accessible, yet poorly known. Thus, for those of us living in the insular Caribbean, PFPs offer logistically feasible windows of observation into the structure and function of a complex biological system, i.e., our forest communities, in alignment with one of the aforementioned key biology concepts (Table 1).

Furthermore, following the AAAS (2009) recommendations, we posit that the most effective way to help students learn about biology is to make students active participants in the process of using biological science to help solve a concrete, real-life problem. In that regard, we believe that the use of PFPs can also help foster the development of at least three core competencies in our undergraduate biology students, namely, the ability to apply the process of science, the ability to use quantitative reasoning, and the ability to communicate and collaborate with other disciplines (Table 1), from which at least nine demonstrable practices can be assessed. The ability to apply the process of science implies a recognition that biology is an evidence-based discipline and so requires a thorough understanding of the scientific approach to answer a specific question. It includes, as demonstrable practices: (1) translating a relevant question into hypotheses from which testable predictions can be derived, (2) designing an experiment to answer the question, (3) designing observational strategies and collecting the data, and (4) evaluating the experimental evidence (Fig. 1). An ability to use quantitative reasoning means demonstrating technical skills in collecting, handling, analyzing, and interpreting data to help answer the question; it includes as further demonstrable practices: (5) preparing and interpreting graphs, and (6) applying statistical methods to data (Fig. 1). Embedded in all the above is another demonstrable practice: (7) the ability to solve specific problems or challenges as they arise through the scientific process. Finally, an ability to communicate and collaborate with other disciplines will necessarily entail: (8) scientific writing, and (9) explaining scientific concepts and interpretations to different audiences (Fig. 1). One main goal is to ensure that the student is, from beginning to end, actively and intimately involved in each of the steps associated with the acquisition of the above skills. Below we briefly review some of the specific aspects associated with PFPs that could be used to help develop each demonstrable practice so as to ultimately answer relevant questions about the structure and function of forested communities.

From abstract concepts to concrete hypotheses

Biology instructors should focus on helping students to develop an understanding of key biological concepts, which might require sacrificing factual-knowledge content that is not absolutely necessary or by addressing fewer concepts but doing so in greater depth (AAAS 2009). It seems reasonable to suggest that examining the students' ability to translate abstract biological concepts into concrete questions from which hypotheses and testable predictions can be derived is a tractable way to assess how well the student understands such concepts.

Table 1. List of core concepts and competencies that undergraduate biology students need to develop based on the AAAS (2009) report.

Core concepts for biological literacy	Core competencies
Evolution	Ability to apply the process of science
Structure and function	Ability to use quantitative reasoning
Information flow, exchange, and storage	Ability to use modeling and simulation
Pathways and transformations of energy and matter	Ability to tap into interdisciplinary nature of science
Systems	Ability to communicate and collaborate with other disciplines
	Ability to understand the relationship between science and society

Permanent forestry plots have provided, and will continue to provide, a wealth of data for the advancement of our understanding of concepts, patterns, and processes in complex living systems (Wolf et al. 2009 and references therein); thus, their inherent great value as part of the scientific process is not in question. The challenge is to find ways in which these plots can be effectively integrated into the

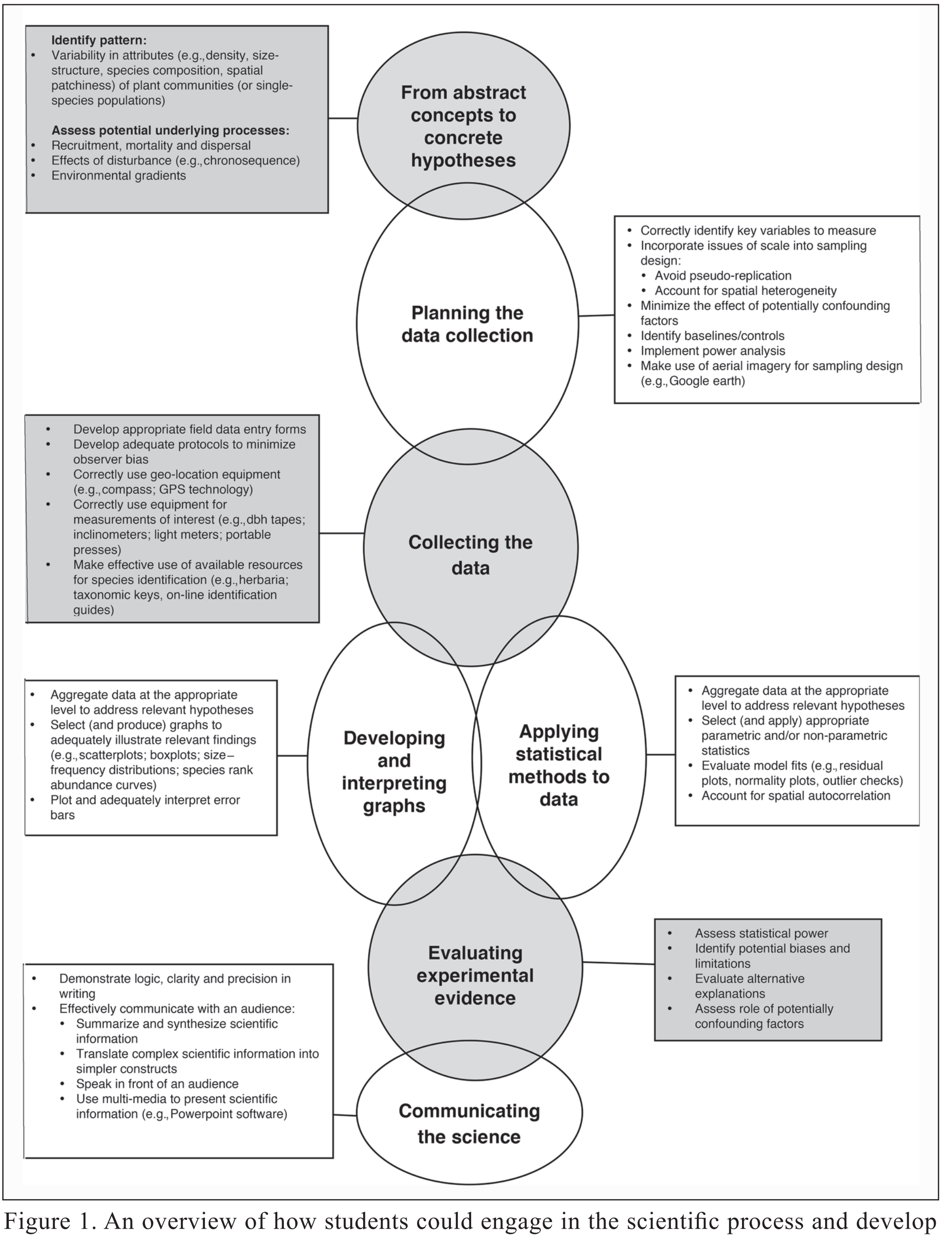

Figure 1. An overview of how students could engage in the scientific process and develop core competencies in Biology using permanent forestry plots (PFPs).

typical one-semester biology undergraduate course, during which there is a very narrow window of contact between the students and the study-system; thus, the focus should be on a limited range of questions and derived hypotheses that can be effectively tested with the students' direct participation. In spite of these limitations, our experience suggests that opportunities to do so exist and that they should be seized whenever possible because we believe that the hands-on, inquiry-driven, nature of the process is more important than the final research outcome.

Clearly, within a narrow timeframe, the most straightforward questions about structure and function that undergraduate students can ask using PFPs pertain to spatial variability in attributes of single species or selected subsets of species within plant communities, and about some of the biotic and abiotic factors that influence such variability. For example, this work could involve investigating patterns in species composition along environmental gradients or, in the absence of environmental data, examining the spatial structure of plant communities as related to competition or dispersal (Fig. 1). Alternatively, in situations where PFPs within a broadly similar environment are comprised of plant communities at different times after disturbance, they could be used for space-for-time substitutions to investigate succession dynamics (e.g., chronosequences) (Fig. 1). For example, due to the gradual abandonment of *Saccharum* spp. (sugarcane) fields in Barbados, forest cover has increased almost ten-fold over five decades through natural regeneration (Helmer et al. 2008); these forests have markedly different ages. The shared history of many of these fields makes this system particularly amenable to studies of succession through permanent plots that capture a chronosequence. As such, relevant soluble questions could focus on the rate of forest regeneration, the identity of the species involved (e.g., native and endemic versus introduced) in the different seral stages, and/or the weight of the evidence helping distinguish among specific causes and mechanisms of successional change (see also Bakker et al. 1996).

The specific question(s) will likely be context-dependent. Importantly, because PFP studies imply availability of preliminary data, these data can be used in the classroom to ensure that whatever question is asked is sensible. Use of existing PFP data should streamline the process by minimizing the need for pilot studies. The key element is to make the students participate in the formulation of sensible candidate hypotheses aimed at explaining the patterns observed and in the identification of predictions helping discriminate among competing hypotheses.

Experimental design: Planning the data collection

With a specific question and a derived set of hypotheses and predictions aimed at helping explain the variability in some aspect of the plant system, students should participate in the design of the data-collection process. They should help decide which PFPs should be used and how, and which variables should be prioritized for measurement and why (Fig. 1). The elaboration of a reasonably solid design would be a strong indicator of a good understanding of both the question that is being asked and the system in which the study will take place. Clearly, the adequacy of the design would have to be assessed within the constraints of a short-term research inquiry and the purely observational (non-manipulative) nature of the experiment (i.e., a mensurative experiment; sensu Hurlbert 1984). Students and instructors will need to explicitly acknowledge the correlative nature of the findings (i.e., difficulty in attributing causation) and the potential influence on the PFPs of confounding spatial and environmental factors operating at a range of scales. In this context, the use of PFPs would represent an opportunity to introduce the student to important universal concepts of experimental design such as replication, random sampling, and pseudo-replication (Hurlbert 1984), as well as to important phenomena typical of natural systems examined in the spatial domain such as spatial autocorrelation (Fig. 1) (Legendre 1993). These potential studies utilizing PFPs also represent opportunities to introduce students to free, user-friendly tools that can be useful for designing the spatial sampling of large areas, such as Google Earth. In a more advanced quantitative setting, and depending on the question asked, PFPs could also be used to familiarize students with statistical concepts of effect size, sample size, and random variation, which are the basis of power analysis. For example, students might compare the precision of density estimates between rare and abundant co-occurring plant species.

Observational strategies: Collecting the data

There are at least three critical areas in which the data-collection stage could significantly contribute to the development of competencies by the student. First, data-collection can help consolidate the students' understanding of the scientific process being undertaken. In that regard, we think that students should be closely involved in the development of the field forms for data entry (Fig. 1). For the experienced field researcher, this might appear a trivial exercise, but many of our students struggle with this component because it requires visualizing the transition from an idea (e.g., measuring canopy cover) to an actual set of concrete values. It therefore requires anticipating what the data are going to look like and forces the student to distinguish and select among different types of variables (ratio, nominal, interval, and ordinal scales) and about the potentially nested structure of the data (e.g., measurements of multiple trees within a plot versus a single elevation measurement for an entire plot). A useful follow-up exercise is to have the students also participate in the conceptualization of the electronic databases (e.g., distinguishing between variables and observations and/or identifying grouping variables) where these data will be entered and stored for subsequent graph production and statistical analysis.

Second, the data-collection process should, of course, lead to data collection by the students, and in doing so help them to develop an array of valuable field skills relevant to the study-system (Fig. 1). The main barrier to data collection in PFPs by our biology undergradates is plant identification. We believe that PFPs can provide students with an opportunity to acquire the skills necessary to recognize a portion of what at the start appears to them as a monolithic assemblage of plants. Although there are published floras for most Caribbean islands, many of these are out of print (e.g., Adams 1972, Howard 1977–1989), and even when they are available, their technical language makes them often incomprehensible to today's undergraduates. However, with expert assistance in the field, students can learn to recognize individual flowering-plant families with distinctive vegetative features and, by narrowing down their options to single families, plant identification becomes less daunting. A number of floras geared toward the general public with full color photographs are available for specific islands of the Caribbean (e.g., Carrington 2007, Hawthorne et al. 2004, Pratt et al. 2009), and a combination of these and several websites available on Caribbean plants (e.g., Acevedo-Rodríguez and Strong 2007, Broome et al. 2007, Graveson 2010, Mori et al. 2007) have made plant identification much more accessible to non-scientists. Furthermore, this endeavour provides an opportunity to collect unidentifiable specimens so that students become aware and make use of the herbarium collections that are available on-line or within universities, non-governmental organizations, and government departments, so as to highlight the tremendous value of such natural history resources.

Data collection will also involve the development of demonstrable field skills that go beyond plant identification. Such field skills will depend on the questions being asked, but it is likely that students will learn to: (1) estimate attributes of individual plants such as diameter at breast height (dbh) and/or total height of trees, (2) use sub-plots to estimate density of abundant growth forms such as seedlings and saplings (regeneration) and/or sub-canopy species, and (3) estimate environmental attributes of the PFPs such as soil characteristics and/or percent canopy cover. Another skill to be gained is the ability to develop maps showing the location of plants within a plot, if spatial patterning at that scale is of interest. Implicit in the application of these skills by the students is learning how to use a wide range of field tools such as portable plant presses and secateurs, GPS devices, transect tapes, dbh tapes, calipers, inclinometers, portable quadrats of various sizes, compasses, and/or canopy-cover scales (Fig. 1). In this regard, we have noted that smartphones can be a very practical multi-purpose field tool (e.g., as a camera, map, compass, data-entry device, communication device) that our tech-savvy students are happy to use. During this field-work, opportunities will arise for students to work in groups that deal with different tasks so as to make more efficient use of the limited time that is allocated to data collection. Group work also affords a good opportunity for students to share whatever knowledge and experience they might already possess regarding natural history and/or data collection with their peers. Furthermore, prior to or during the very early stages of the field work, students should be encouraged to think about how they will address potentially important issues of observer bias and calibration of measurements (Fig. 1).

Third and finally, beyond the consolidation of the understanding of the scientific process and the acquisition of a valuable set of field skills, the data-collection process forces students to connect with nature. We believe that this element of the undergraduate biology experience is as important as the others; when a student no longer needs to point to a tree because he/she does not know its name, we have already made a first step toward winning the battle against the worrisome trend of alienation from nature that we see in our undergraduate biology students. We also believe that by integrating the acquisition of this new knowledge in natural history into the students' scientific experience, we increase the chances that such knowledge will be theirs for a lifetime.

Developing and interpreting graphs and applying statistical methods to data

Once students have collected a dataset, the most straightforward way to assess the level of support for the different hypotheses is the visual inspection of the data through the production of pertinent graphs. There are a wide range of plausible and simple graphical representations of data for PFPs, including scatter-plots illustrating relationships between biological attributes of plant communities (e.g., relative abundance of different growth forms or selected species) and environmental variables (e.g., altitude, canopy cover), species accumulation curves, size–frequency distributions, and bar charts or boxplots illustrating differences in biotic or abiotic attributes between areas or habitats of interest (Fig. 1). In our experience, determining exactly what needs to be plotted and how the data need to be handled to produce such plots is particularly challenging for those students who have not fully grasped the rationale behind the steps that ultimately lead to the production of the data-set and the intricacies of the experimental design. Thus, graph preparation represents an important stage in the overall assessment of the students' competencies that should go beyond technical ability to produce graphs using popular software. Furhtermore, if students have been formally trained in statistics, such graphs should be supplemented with the results and interpretation of tests assessing the statistical significance of the findings. This task provides an opportunity to assess the student's ability to select and apply the most appropriate statistical procedures in a real-life situation (e.g., formulating appropriate statistical null hypotheses and selecting between parametric and non-parametric procedures to test them) given the data and specific questions at hand (Fig. 1).

Evaluating experimental evidence

There is little doubt that the correlative and short-term nature of PFP studies in the context of an undergraduate biology class can considerably constrain the generality, depth, and robustness of the study's findings. We therefore must reiterate that the hands-on and inquiry-driven process here is more important than the final outcome of the analyses. Thus, a thorough identification of the types, causes, and consequences of the factors limiting the general applicability of the study's findings can be in itself a useful exercise to reinforce the abilities acquired by the student during the different steps of the process. Students might identify biases, confounding factors, and/or alternative explanations that could not be distinguished on the basis of their predictions and postulate how a better control of those factors could have been exerted in an observational and/or manipulative context (Fig. 1).

Communicating the science

In a world where environmental policy-makers are increasingly looking towards the scientific community for answers, effectively communicating about science to a diverse audience is now widely regarded as an integral, yet also challenging, part of the scientific endeavour. It leaves little room to doubt that students that think clearly and logically will be able to communicate more effectively. In that regard, we would like to stress the importance of writing in the overall scientific process as we support the idea that there is a close two-way relationship between thinking and writing: shereas it is impossible to write about science well without clear thinking, the writing process itself (when carefully guided) should help students think more clearly (Woodford 1968). Thus, the use of PFP studies should involve guided writing exercises to help students (1) develop logical thinking and precision in writing, and (2) consolidate their understanding of the entire scientific process. With this strong foundation, students should be able to summarize and synthesize the results of their work and effectively communicate them to a variety of audiences within and outside the scientific community (Fig. 1).

Concluding Remarks

We have made the case that PFPs can be effective tools to help develop biology literacy and reverse the trend toward detachment from nature that we see in our students. However, we admit that for many of our students, the degree to which we achieve these goals is likely to depend on their perception of the relevance of the problem to their daily or future lives. Thus, we believe that, to be most effective, the use of PFPs should be integrated into a background discussion on the global, regional, and/or local environmental issues that are likely to be most relevant to the students and on how science can help address these issues. The latter applies to the use of any other learning–teaching tool and natural study-system for the development of biology literacy, and it touches upon another important core competency expected from a biology undergraduate student, namely, the ability to understand the relationship between science and society (Table 1).

To illustrate the point, and with regard to our local environment, the Barbadian historian Dr. Karl Watson has recently publicly raised his concern that Barbados is becoming a "concrete jungle" as increasing amounts of fertile land are turned into housing developments (Evanson 2014). Although his remark relates mainly to the issue of loss of opportunities in ensuring food security through the progressive loss of cultivated land, it raises the important question of how abandoned agricultural land should be used in Barbados. Allowing some of that land to be used in the future for forestry purposes by facilitating natural forest regeneration seems another legitimate option that should be put on the table. In this context, PFPs could be particularly valuable to inform the decision-making process and help ensure science-based policies, making their use more clearly relevant to all Barbadians.

Finally, we have focused exclusively on the structure of vascular plant communities as an example of study systems because such communities are most readily observable and measurable, and their composition is most easily identifiable by inexperienced students. However, PFPs might also offer great opportunities as windows of observation into systems relevant to other sub-disciplines of biology including plant ecophysiology, environmental biology, zoology, mycology, and quantitative biology among others. Thus, PFPs could potentially provide multiple benefits to a diverse group of researchers and undergraduate courses, highlighting the interdisciplinary nature of biology and, importantly, increasing the cost-effectiveness of implementing PFPs programs.

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