DEPARTMENTS

Ecology 101

Note: William Bromer is the new editor of **Ecology 101**. Anyone wishing to contribute articles or reviews to this section should contact him at the Department of Natural Sciences, University of St. Francis, 500 N. Wilcox, Joliet, IL 60435, (815) 740-3467, e-mail: wbromer@stfrancis.edu.

EcoSampler: A Learning Object for Community Sampling, Community Structure, and Succession

Understanding basic concepts such as community structure, species diversity, and succession, as well as the possible causes of variation in species distribution and dispersion, is fundamental to undergraduate ecology courses. Given that determining species diversity or successional patterns requires knowledge of species abundances, it is important that students are also familiar with sampling theory, specifically how to draw an impartial sample of individuals from a community. Although outdoor exercises allow students to gain valuable experience in community ecology through sampling living communities, in large introductory courses, in winter-term courses, or in courses that survey a wide array of ecological topics, there are often too few laboratory periods to include outdoor exercises.

We developed a web-based learning object, *EcoSampler* ‹http://www.departments.bucknell.edu/biology/courses/biol208/EcoSampler/› to provide Bucknell University majors in biology, animal behavior, and environmental studies with virtual experience sampling communities while facilitating their learning about community structure, species diversity, and succession. Here we offer an overview of *EcoSampler* and describe how we use this web-based simulation model in a sophomore-level Population and Community Biology (BIOL 208) course. Our students, paired on computers, use *EcoSampler* during one 3-hour laboratory session. Students interpret *EcoSampler*'s output and prepare a written report, which is due at the following week's laboratory meeting. *EcoSampler,* which is freely available via the Web, also can be used in other ways, including as a homework assignment to supplement lecture materials or as an exercise that is part of an online course. Regardless of how *EcoSampler* is used, our experience suggests that it provides students with a strong conceptual and methodical background, and that it is very effective when coupled with a subsequent or concurrent field trip that involves community sampling. Instructions for *EcoSampler* are included online, so this article is intended to provide an overview of our learning object and to describe how we use it in our Bucknell University course.

EcoSampler analyzes two digitized Pennsylvania old-growth forests using either area (quadrat) or distance (point-quarter) sampling methods with haphazard, random, or systematic sample-selection protocols. Because *EcoSampler* estimates the amount of field time necessary for each methodology, students discover that the efficiencies of sampling methods vary. In addition, they learn that sample bias differs among haphazard, random, and systematic sampling protocols, and that species differ in their spatial distributions. *EcoSampler*'s summary of basal diameter size-class distributions facilitates predictions about the successional trends in the sampled communities, and its calculation of species richness and diversity enables comparison of the community structures of the two virtual forests. An obvious advantage of this learning object is that large numbers of students can simultaneously sample and analyze forest community data using several sampling criteria and methodologies, and they can gain appreciation of fundamental ecological concepts as they interpret their results. We use the 18 questions included with *EcoSampler* to guide our students' interpretation of results and frame their written reports.

The objectives of *EcoSampler* include: (1) understanding sampling theory as applied to community ecology; (2) gaining understanding of area and distance-sampling methods and contrasting their advantages and disadvantages; (3) comparing sample bias with haphazard, random, and systematic sampling protocols; (4) learning about the measurement of species abundance (e.g., density, dominance, frequency), species dispersion, and community structure; (5) gaining understanding of ecological succession and species replacement; and (6) communicating results and conclusions via a written report.

The digitized virtual forests

Mohn Mill Natural Area

The Mohn Mill virtual forest is based on tree density, dominance, and frequency results from Abrahamson and Gohn's (2004) field study (Fig. 1). This species-rich virtual forest is particularly useful to explore sampling protocols as well as species dispersion and the effects of disturbance in bringing about successional change. Located in central Pennsylvania, the 154-ha Mohn Mill site (41°4′ N, 77°8′ W) includes bottomlands as well as gentle to steep slopes. Elevations range from 420 to 570 m above mean sea level. The area's sandstone-derived soils include loams, sandy loams, and stony to very stony loams. The Mohn Mill area was logged between 1904 and 1912 during the period identified as the "clear-cut or hemlock-chemical wood" era but the area has not experienced timber extraction since. Chestnut blight eliminated the American chestnut from the site's canopy during the 1930s, which likely facilitated additional dominance by oaks. The site experienced gypsy moth outbreaks from 1979 to 1982 and during 1996, and severe windstorms as well as ice and wet snow events have impacted the forest's canopy. Currently, white-tailed deer (*Odocoileus virginianus* browsing is inhibiting oak regeneration, and acid precipitation may be influencing the acidic soils and plant performance (Abrahamson and Gohn 2004).

The Mohn Mill area is a Pennsylvania Department of Conservation and Natural Resources proposed wild-plant sanctuary in part because of the presence of the federally endangered northeastern bulrush (*Scirpus ancistrochaetus* Schuyler). The small, seasonal ponds that harbor northeastern bulrush occur within an oak-canopied forest matrix that is likely crucial to the long-term survival of this plant. Although the Mohn Mill site is protected from logging, Abrahamson and Gohn (2004) showed that the site is experiencing a replacement of white, chestnut, red, and black oaks by more shade-tolerant red maple and eastern hemlock. As the overstory oaks age and die, oaks are replaced disproportionately by red maple and eastern hemlock depending on microsite conditions. This transition will have major implications for understory plants, including the persistence of the northeastern bulrush, because of reduced available light. *EcoSampler*'s tree size-class histograms help students understand such species replacements and the consequences of succession.

Snyder-Middleswarth State Park Natural Area

The Snyder-Middleswarth virtual forest is based on tree density, dominance, and frequency results from a field study by Zawadzkas and Abrahamson (2003: Fig. 1). This virtual forest has limited tree-species diversity, which offers a useful contrast to the Mohn Mill forest. Because it has marked topographic variety, this forest is useful to explore the patterns of species occurrence and dispersion in relation to spatial variation and edaphic conditions. The Snyder-Middleswarth Natural Area (40°48′ N, 77°19′ W) in central Pennsylvania is among the largest of the few old-growth eastern hemlock–yellow birch forests remaining in Pennsylvania. Thanks originally to inaccessibility and in 1965 to its designation as a *National Natural Landmark,* a 135-ha portion of this forest has never been logged.

The Snyder-Middleswarth forest is located in a narrow and steep ravine between two east- and west-running ridges, and as a consequence the ravine has well-developed north-facing and south-facing slopes as well as a bottomland and ridge-top community. Slopes vary in steepness up to 68% with elevations ranging from 450 to 550 m. The soils are extremely stony and sandy well-drained loams that have weathered from Tuscarora sandstone. These soils have low to moderate available water capacity and have virtually no pH buffering capacity. As a consequence, acid precipitation is further acidifying the already acidic soils, which is likely impacting on plant performance.

While there are recurrent natural disturbances within this forest including windstorms, especially those associated with snow or ice events, disturbance from acid precipitation and hemlock woolly adelgid are the most serious threats (Zawadzkas and Abrahamson 2003). The latter threatens the continued domination of the old-growth forest by eastern hemlock. Gypsy moth outbreaks since the mid-1970s have impacted the oak canopies of the south-facing slope and ridge tops during multiple growing seasons, and browsing by white-tailed deer is limiting tree regeneration. Sampling the Snyder-Middleswarth virtual forest facilitates student examination of species dispersion and distribution and the consequences of disturbances to succession.

Issues addressed: Five assignments

1. The reliabilities of haphazard, random, and systematic sampling protocols. Students learn that haphazard sampling introduces bias and that systematic or random protocols avoid bias much better.

2. The efficiencies of area and distance sampling protocols. Students discover that one protocol may be a better choice than the other depending on the community.

3. Succession and the spatial-occurrence patterns of forest trees. Students examine the successional status of individual forest species and use life-history attributes of species to consider why a given species has its specific distributions within a forest mosaic.

4. Community structure. Students recognize that diversity indices are dependent on both species richness and species evenness and that both measures are important to understanding community structure.

5. Patterns of species occurrence and abundance due to spatial variation in topography and/or edaphic conditions. Students discover that north-facing and south-facing slopes as well as ridge tops and bottomlands have different species composition and abundance. They also realize that forest trees are differentially adapted to environmental conditions.

Assignment 1: Haphazard, Random, and Systematic Sampling Protocols.—This assignment investigates sampling bias among haphazard, random, and systematic sampling protocols with the Mohn Mill mixed oak–red maple virtual forest. Students are presented an aerial "community view" of the Mohn Mill forest and sample to determine the abundances of the tree species within the community (Fig. 2). Without prior discussion of sampling bias, samples are almost inevitably drawn disproportionately from the center portion of the community. Because of the nonuniform distributions of species, such repeated sampling of a limited portion of the virtual forest generates a biased sample in which some species are oversampled while others are undersampled. Next we have our students draw their samples using random and then systematic sampling protocols. Students compare species-abundance estimates obtained with each protocol to the community's actual abundance measures, which enables them to gain an understanding of strengths and weaknesses of each protocol (Fig. 3).

During each assignment, students must determine when the virtual community is adequately sampled by examining a graph of the cumulative number of species sampled vs. the number or area of samples taken. Species–area graphs generated by our model provide students with a semi-objective means to determine the area or number of plots to sample (Fig. 2).

Each assignment is accompanied by a set of questions designed to guide the students' interpretation of results and evaluate their understanding. In assignment 1 these questions examine the reliabilities of haphazard, random, and systematic sampling by comparing the estimated values based on sampling to actual values. Students conclude that haphazard sampling can introduce bias. Students are then asked to reflect on the efficiencies of random versus systematic sampling in the field using the estimates of time commitment for each sampling (Fig. 3). Students recognize the tradeoff of collecting many samples to gain accuracy in measures of rarer species versus the time and cost of obtaining numerous samples. Students then compare the accuracy of their estimated abundance measures for common versus rare species against actual values. They discover that estimates for rare species are less reliable than those for common species. A final component of assignment 1 asks students to describe the population structure for the most common species by examining its density, dominance, frequency, and importance. Using histograms of tree sizes (Fig. 3), they can determine whether a given species is invading or dropping out of the sampled community or whether its population is stable. Information about the species' natural history, available within *EcoSampler*, helps connect the virtual forest trees with tree life-history traits (Fig. 2).

Assignment 2: Area vs. Distance Sampling Protocols.—The second assignment uses point-quarter sampling of the Mohn Mill virtual forest and compares the results to those from assignment 1, which employs area sampling. Students learn that the point-quarter method is well suited for sampling widely spaced individuals or large individuals (*e.g.*, trees). Assignment 2 questions focus on (1) when area vs. distance sampling would be preferred; (2) whether equal numbers of quadrats and points provide the same reliability for abundance measures; (3) species richness and its meaning; and (4) the meaning of importance values and how two species could have identical importance values yet quite different abundance measures.

Assignment 3: Dispersion and Succession.—Species dispersion, using the Morisita Index of Dispersion (Morisita 1959, Brower et al. 1998), and secondary succession are explored using the Mohn Mill virtual forest. Questions direct students to interpret the dispersion indices of species, most of which are aggregated. Using the life-history information that is available for each species (Fig. 2), students make connections between life-history traits and patterns of dispersion (e.g., clonal propagation of trees and their consequent clumped distribution). The second component of this assignment has students explore the relationship of the Morisita Index and frequency. They find that the two measures are inversely related, and furthermore that frequency, when considered along with density, offers insight into spatial occurrence. Students soon appreciate that frequency, density, and dominance each express different key aspects of population structure.

A third component of assignment 3 investigates succession via an examination of species recruitment with size-class distributions of tree basal areas (Fig. 3). Although tree sizes do not precisely represent tree ages, tree-size data do provide considerable insight into a species' successional status (Skowno et al. 1999). Our questions ask students to predict the future success of dominant trees in the Mohn Mill virtual forest via a comparison of the size-class histograms generated from samples with expected size-class distributions for hypothetical species with stable, successfully invading, unsuccessful or episodic invasion, and senile size-class structures (Fig. 4). A fourth component of assignment 3 is for students to recognize that the size-class distributions at Mohn Mill show little recruitment of oaks but substantial recruitment of red maple, suggesting that the forest is undergoing successional change as oaks are replaced by red maples.

Assignment 4: Community Structure.—While dispersion is a characteristic of populations, measures of species richness and species diversity are characteristics of communities that help assess community structure. To calculate species diversity in the virtual forests, *EcoSampler* uses the popular Shannon-Wiener Index. In this assignment, students sample the Snyder-Middleswarth eastern hemlock–yellow birch virtual forest and compare the species richness and diversity of this forest to these values for the Mohn Mill virtual forest sampled in the previous assignments. They find that Snyder-Middleswarth virtual forest has less species richness and diversity.

Students also compare the size-class distributions for sampled eastern hemlock and yellow birch to theoretical expectations (Fig. 4) and find that both species have stable size-class distributions. Thus, they predict that both species are likely to continue dominance at the site unless disturbances such as hemlock woolly adelgids and/or acid precipitation alter the conditions that favor these species. However, when the size-class distributions of sweet (black) birch are examined, students discover a distribution that suggests an unsuccessful or episodic invasion (Fig. 4) based on limited current recruitment. When available life-history information is considered, students conclude that sweet birch has this size-class distribution because it experiences episodic recruitment due to its dependence on disturbance-generated canopy gaps that enable light levels that support its colonization and establishment.

Assignment 5: Topographic and Edaphic Influences on Plant Distribution.—This assignment examines the variation in species distributions due to topographic and edaphic factors by comparing the north-facing and south-facing slopes as well as the bottomland and ridge top in the Snyder-Middleswarth virtual forest. At the latitude of central Pennsylvania, a 20° south-facing slope receives an average of 40% more midday insolation than a 20° north-facing slope. This difference has a striking effect on the heat budgets and available soil moistures of the two slopes; south-facing slopes are warmer, their evaporation rate is typically 50% higher, and their available soil moisture is lower (Smith and Smith 2001).

Systematic sampling is used to locate quadrats within four of the five labeled subsets of the virtual forest: southern and northern ridge tops, north-facing and south-facing slopes, and bottomland. Students first compare the bottomland, which is dominated by eastern hemlock and yellow birch, to a ridge top, which is covered by red and striped maple, chestnut oak, and sweet birch. The more xeric and higher wind-damaged ridge-top conditions are more suitable for shorter-lived and colonizing species. Next students compare the more xeric south-facing with the more mesic north-facing slope. They find that the south-facing slope has more chestnut oak and red maple, while the north-facing slope has more eastern hemlock, white pine, and sweet birch. Finally, students describe the population structure of chestnut oak on the south-facing slope.

Assessment of student learning outcomes

The learning outcome of *EcoSampler* exercises can be assessed in a variety of ways. One option is to conduct a pre-lab assessment in order to help prepare students to use *EcoSampler*. Students read the available online introduction, background, and assignments sections before coming to lab. We begin our lab with 30–35 minutes of introduction of relevant concepts (e.g., community structure, succession) because our *EcoSampler* lab exercise comes prior to discussions of community ecology in lecture. (Community ecology is covered in our spring course lectures in the latter portion of the semester when our labs involve field exercises.) We have found that our students need to understand the following points before beginning the *EcoSampler* exercise: (1) a community is an assemblage of interacting populations of species that occupy a given area; (2) a community is characterized by both a physical and biological structure; (3) the mix of species that make up a community defines its biological structure; (4) population interactions such as competition, predation, parasitism, and mutualism influence community organization; (5) the biological structure of a community can be defined, in part, by the density, frequency, and dominance of each of the species that compose the community; (6) spatial variation is part of community structure; and (7) succession of species occurs in communities over time. In order for the exercise to be most effective, students must understand why it is necessary for ecologists to know what species compose a community, how abundant those species are, and if some species are increasing in abundance while others are decreasing over time.

At the conclusion of the introduction to the *EcoSampler* exercise, students could be asked to write a two- or three-minute paper on any misconceptions that they held about key points prior to the lab presentation (Sacchi 2006). Even with a moderately detailed introductory presentation, we have found that our students comfortably complete all five assignments within a three-hour lab period. Instructors who adopt *EcoSampler* can select specific assignments or use all five assignments depending on their audience and time available. Alternatively, instructors can develop their own assignments using *EcoSampler*'s virtual forests and sampling capabilities.

We evaluate our students via written reports (submitted electronically) that are due at the following week's laboratory. Reports are graded using a key and guidelines to standardize evaluation. We would be happy to make this key available to adopting instructors, upon request.

Going beyond the exercises and questions

We encourage our students to consider concepts and issues that lie beyond the scope of the assigned exercises. Discussions in lecture or subsequent labs provide an excellent way to engage students. For example, students can be asked to ponder the value of having measures of species abundances within a community that are taken at different times along a timeline (i.e., having a baseline against which future measures of species abundances within that community can be compared). They should consider the types of questions that can be answered with such timelines to understand species change and succession, impacts of land-management plans, development of conservation plans for natural areas, or recovery plans for threatened or endangered species.

Alternatively, a discussion of the reasons why plants show clumped distributions can challenge students to consider life-history traits. Such discussions help students understand that environmental gradients are the rule in nature, so that a site that is good for one individual of a given species is likely to be good for other individuals of that species. Students might also realize that there are forces in nature that counteract clumping. Competition among individuals for water in deserts or light in forests can favor regular spacing, as can damage done by plant antagonists such as herbivores or pathogens that more easily find clumped host plants (Barbour et al. 1999).

We have found that conversations about community structure and species diversity can probe the degree of student understanding of the complexity of trophic interactions within communities of differing species diversity. For example, communities with high species diversity may have more complex and varied interactions (e.g., energy transfer, predation, competition) among species than communities of low diversity.

A final example is especially pertinent for "pre-med" majors: it involves a discussion of the importance of statistically valid sampling methods in determining the efficacy of new medicines and the responses of cells to various treatments.

Programming details

EcoSampler is hosted on a web server at Bucknell University. The client side runs well on either a Windows-platform PC running Internet Explorer or Mozilla Firefox or a Macintosh computer running Safari or Internet Explorer. Cookies and JavaScript must be enabled. The preferred screen resolution is 1280 × 1024, but should be at least 1024 × 768 in order to view pages. DSL/Cable Modem or higher is the preferred connection because *EcoSampler* is graphically rich.

The simulation model is implemented using Active Server Pages (ASP)/VBScript via Internet Information Services (IIS) 6.0. Community data are stored in a Microsoft Access database, and *EcoSampler*'s code makes extensive uses of IIS session variables for storing data as the community is sampled. Output is standard HTML, with tables used to format various views of the community. The HTML includes a limited use of JavaScript, primarily to prevent problems from using the Back button. In addition to the basic functionality, *EcoSampler* includes several "administrative" scripts for generating community data.

Summary

Introductory ecology courses include discussions of community structure, species diversity, and succession. Appreciation of sampling theory is essential to student understanding of these and other ecological concepts. Using data from two Pennsylvania forests, an old-growth eastern hemlock/yellow birch community and a mixed oak/red maple community uncut since the early 1900s, web-based *EcoSampler*'s virtual forests facilitate student investigation of sampling theory, community structure, and succession. The model employs area (quadrat) or distance (point-quarter) methods, with haphazard, random, or systematic sampling protocols. Students learn how to recognize when they have adequately sampled a community and a "time/effort" function permits students to assess the labor trade-offs of sampling protocols. Output from *EcoSampler* includes absolute and relative measures of species density, frequency, dominance, and importance, size-class distributions, and dispersion, as well as species diversity and natural history information about each species. *EcoSampler*'s five assignments examine (1) potential for bias in haphazard, random, and systematic sampling protocols; (2) area vs. distance sampling procedures; (3) species dispersion and successional trends based on analysis of size-class distributions; (4) community structure via species diversity; and (5) variation in species distribution due to topographic and edaphic factors. *EcoSampler* is freely available using high-speed, internet-connected Windows or Macintosh computers as we described above, as homework assignments, or projects for an online course.

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Literature cited

Abrahamson, W. G., and A. C. Gohn. 2004. Classification and successional changes on mixed-oak forests at the Mohn Mill Area, Pennsylvania. Castanea 69:194–206.

Barbour, M. G., J. H. Burk, W. D. Pitts, F. S. Gilliam, and M. W. Schwartz. 1999. Terrestrial plant ecology. Third edition. Benjamin Cummings, Menlo Park, California, USA.

Brower, J. E., J. H. Zar, and C. N. von Ende. 1998. Field and laboratory methods for general ecology. Fourth edition. William C. Brown, Dubuque, Iowa, USA.

Curtis, J. T., and G. Cottam. 1962. Plant ecology workbook: laboratory, field and reference manual. Burgess, Minneapolis, Minnesota, USA.

Elias, T. S. 1980. The complete trees of North America: field guide and natural history. Van Nostrand Reinhold, New York, New York, USA.

Morisita, M. 1959. Measuring the dispersion of individuals and analysis of the distributional patterns. Memoirs of the Faculty of Science, Kyushu University, Series E (Biology) 2:215–235.

Sacchi, C. F. 2006. Testing hypotheses about herbivore responses to plant vigor and herbivore impact on plant reproduction. Teaching Issues and Experiments in Ecology 4:1–23.

Skowno, A. L., J. J. Midgley, W. J. Bond, and D. Balfour. 1999. Secondary succession in *Acacia nilotica* (L.) savanna in the Hluhluwe Game Reserve, South Africa. Plant Ecology 145:1–9.

Smith, R. L., and T. M. Smith. 2001. Ecology and field biology. Sixth edition. Benjamin Cummings, San Francisco, California, USA .

Zawadzkas, P. P., and W. G. Abrahamson. 2003. Composition and tree-size distributions of the Snyder-Middleswarth Old-Growth Forest, Snyder County, Pennsylvania. Castanea 68:31–42.

Internet link:

‹http://www.departments.bucknell.edu/biology/courses/biol208/EcoSampler/›

Warren G. Abrahamson[1] and Michael R. Weaver[2]
[1]Department of Biology and [2]Library and Information Technology
Bucknell University
Lewisburg, PA 17837 USA
Correspondence: Warren Abrahamson (570) 577-1155
E-mail: warren.abrahamson@bucknell.edu

Figures relating to this article appear on the following pages.

Figure 1.

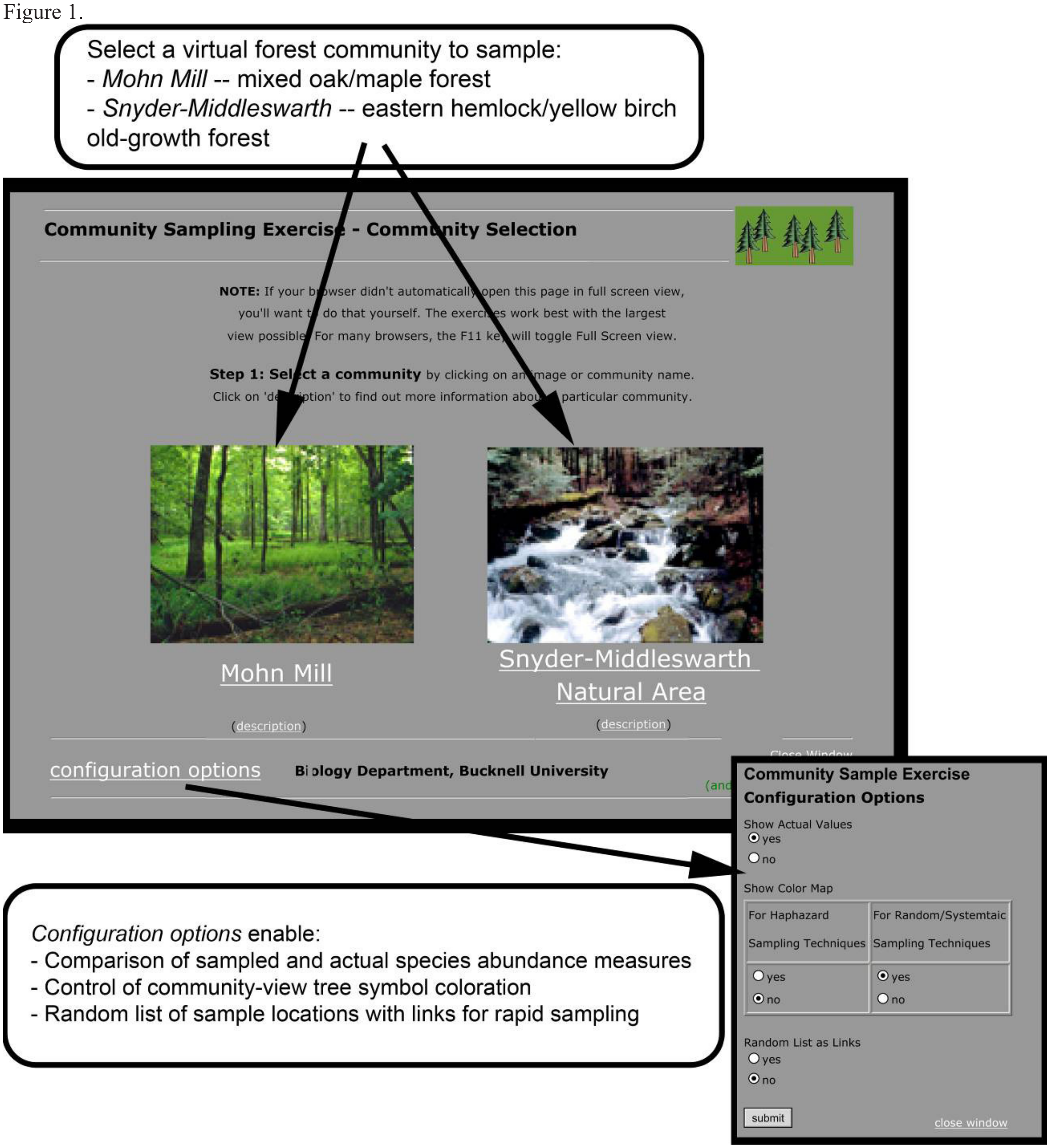

Fig. 1. Selection of the virtual forest to sample involves an interface that also facilitates control of the appearance of the simulation model.

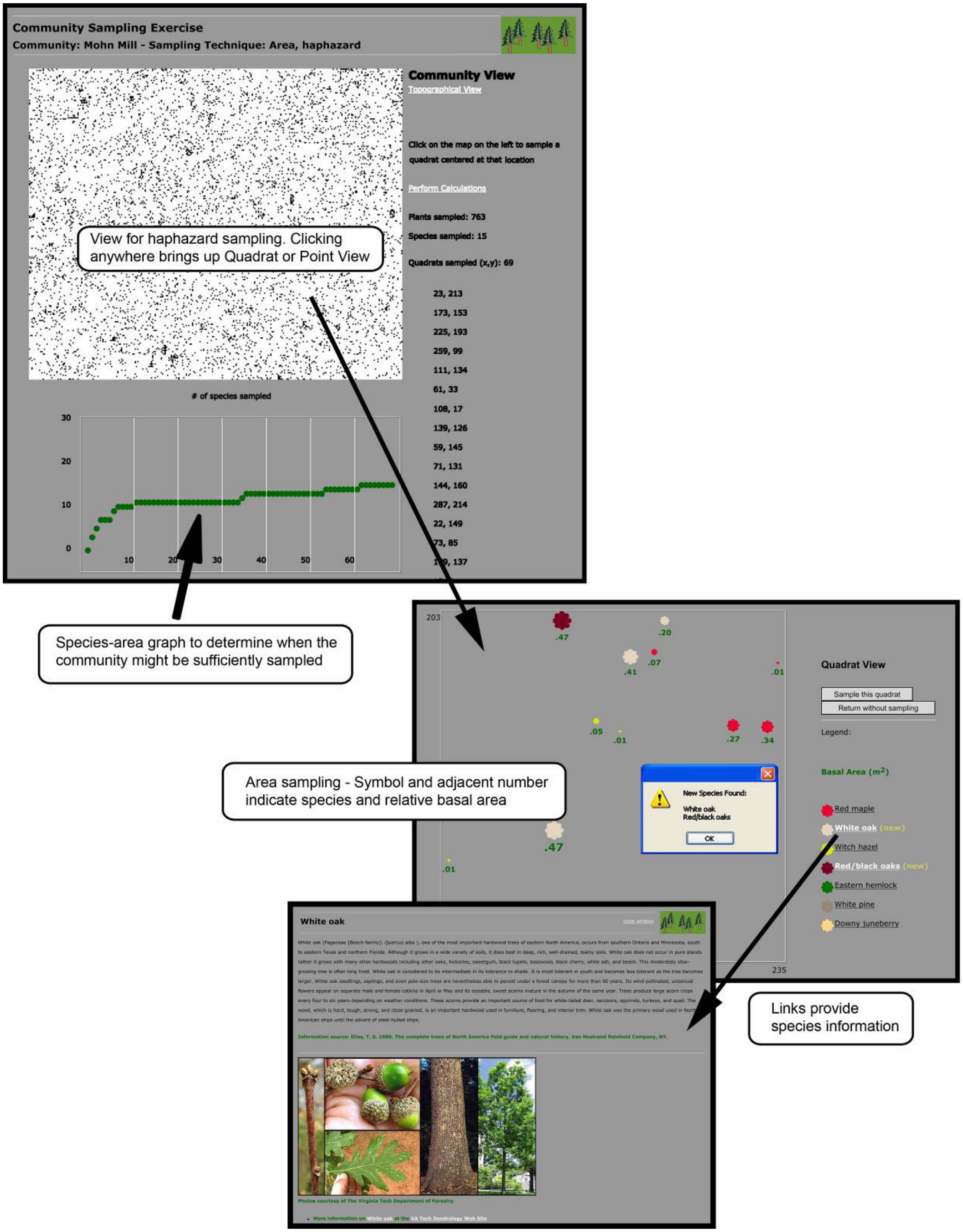

Fig. 2. Community and Quadrat views of the Mohn Mill virtual forest. Colored symbols indicate the identity, size, and location of individual trees. The virtual forest can be sampled with or without an overlaid grid of quadrats or points that can be sampled haphazardly, randomly, or systematically.

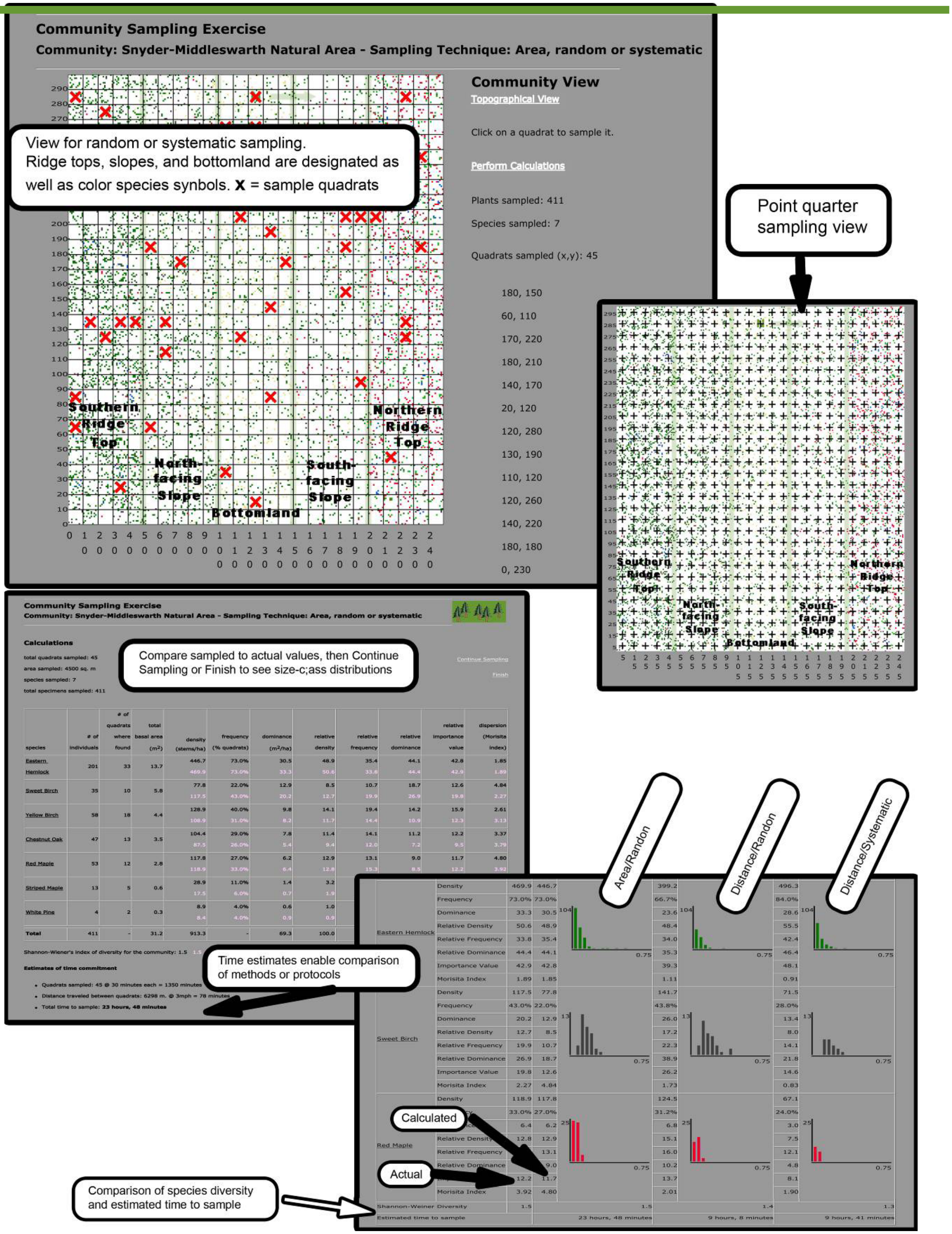

Fig. 3. Community view showing sampled quadrats (quadrats with Xs), topographical view option, and point-quarter sampling view along with example output for the Snyder-Middleswarth Natural Area.

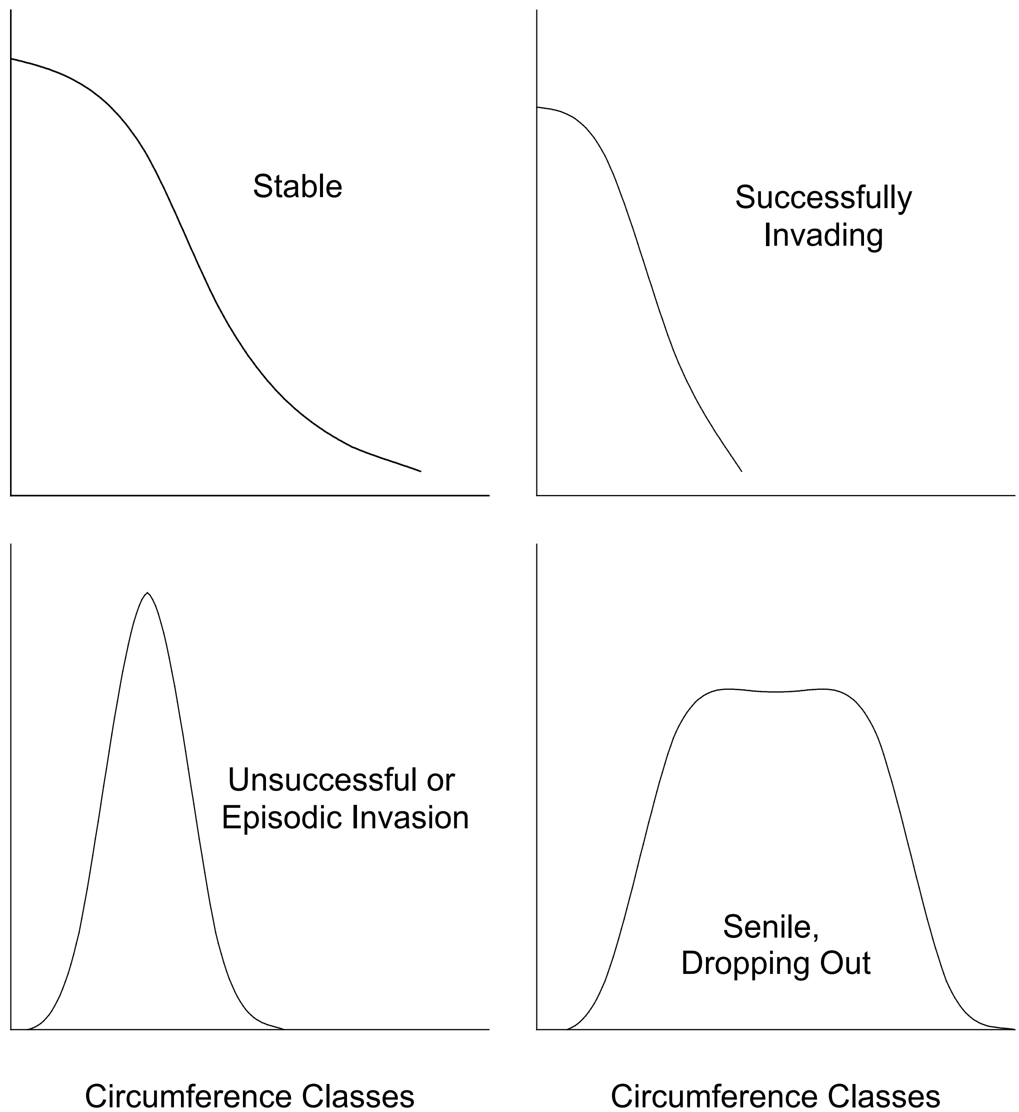

Fig. 4. Expected size-class distributions for trees showing stable, successfully invading, unsuccessful or episodic invasion, and senile, dropping-out populations.