

EXPERIMENTS

Effects of Eastern Hemlock (*Tsuga canadensis*) on the Establishment of Interspecific Seedlings

Greg Murray and Kathy Winnett-Murray,
Department of Biology, Hope College,
Holland, MI, 49422
gmurray@hope.edu and winnettmurray@hope.edu



photo of *Tsuga caroliniana*
© JD Skean 2000

ABSTRACT:

In this guided inquiry, students investigate the inhibitory effects of Eastern Hemlock trees on establishment of neighboring woody plants. First, students travel to a mixed-stand hemlock, beech, and maple forest and observe spatial distribution patterns of woody seedlings beneath these three species. Groups of students then design experiments investigating 1) allelopathic effects of hemlock, and 2) non-allelopathic habitat differences (e.g. light availability, soil composition, litter) as explanations for differential seedling distribution. Students then spend 3 weeks inside and outside of lab periods collecting and analyzing data testing their hypotheses, and they present their results in an in-class symposium.

Table of Contents:

KEYWORDS, DESCRIPTORS, and SYNOPSIS.....	2
DESCRIPTION OF THE LAB ACTIVITY.....	5
Introduction.....	5
Materials and Methods.....	8
Questions for Further Thought and Discussion.....	9
References and Links.	10
COMMENTS BY CONTRIBUTING AUTHOR(S)	12
Challenges To Anticipate and Solve.....	12
On the Lab Description.....	12
On the Questions for Further Thought and Discussion.....	14
On the Assessment of Student Learning Outcomes.....	15
On the Formative Evaluation of this Experiment	16
On Translating the Activity to Other Scales.....	17
CREDITS AND DISCLAIMERS.....	18

KEYWORD DESCRIPTORS:

Principal Ecological Question Addressed: Do Eastern Hemlock trees inhibit the establishment of woody plants of other species beneath their canopies? If so, what factors are likely to be involved in that inhibition?

Ecological Topic Keywords: community ecology, species interactions, competition, allelopathy, chemical ecology, succession.

Science Methodological Skills Developed: field identification and observation, hypothesis testing, experimental design, evaluating alternative hypotheses, use of spreadsheets and statistical and graphing software, use of primary literature, oral communication.

Pedagogical Methods Used: guided inquiry, student-directed inquiry, cooperative learning, oral communication, written communication, problem-based learning.

CLASS TIME: MULTIWEEK - One lab trip (3 hr lab) is used to introduce students to the field site, the forest community, and the problem. Students make preliminary observations and begin developing a proposal. Student groups carry out investigations independently throughout the rest of the semester; typically 3-4 additional lab period-equivalents are needed for data collection, lab analysis, and preparation of the oral report. Part of one lab period near the end of the semester (ca. 15 mins/group) is devoted to oral group presentations.

OUTSIDE OF CLASS TIME: Students generate their presentations and reports outside of class. Depending on the relative efficiency of different groups, some groups may need or want additional out-of-class time for data collection.

STUDENT PRODUCTS: Students submit (i) a one page research proposal, (ii) a primary literature reference list with a minimum of 12 citations about 1 month in advance of the report due date, (iii) their original data, (iv) a lab report composed according to the guidelines below, and (v) they present an oral report during an in-lab class symposium.

SETTING: Data on the distribution of saplings and seedlings are collected in the field; most groups follow up with laboratory analysis (e.g. soil samples, pH, leaf litter measurements) and/or greenhouse experiments on campus (e.g. effect of soil types on seed germination). This lab can be done in any season, but it is easier to identify seedlings and saplings when leaves are present.

COURSE CONTEXT: Undergraduate course title: Ecology and Evolutionary Biology, class size: 45-75, class Level: undergraduates, primarily sophomores.

INSTITUTION: private undergraduate college.

TRANSFERABILITY: This investigation could be modified as a more structured class project to fit into 1 or 2 lab periods and for larger universities (all students do the same investigation, or groups work on assigned sub-topics). Competitive inhibition in other plant communities can be investigated using the same guidelines used for this lab, but focusing on the potential inhibitory effects of different plant species, e.g. *Ailanthus*.

SYNOPSIS OF THE LAB ACTIVITY (audience: students)

WHAT HAPPENS:

In this guided inquiry, students investigate hypothesized inhibitory effects of Eastern Hemlock trees on the establishment of neighboring woody plants. First, students travel to the study area (Hope College Biology Nature Preserve - a 50 acre parcel of beech-maple "dune" forest) and observe spatial distribution patterns of seedlings that could be explained by competitive inhibition. Following an hour or so of observations, students collect raw data on the occurrence of woody seedlings beneath adult Eastern Hemlock vs. neighboring forest patches under adult American Beech (*Fagus grandifolia*) and/or Sugar Maple (*Acer saccharus*). Class data is pooled, and the entire class performs a paired-samples t-test which, at our site, shows a significant reduction of woody seedlings beneath Eastern Hemlock as compared with adjacent sites beneath beech or maple. Next, students are challenged to design a follow-up field and/or lab investigation of interest to them (and that we approve) to explore two alternative hypotheses to explain the initial results. Both hypotheses involve competitive inhibition, but one hypothesis must invoke some form of allelopathic cause for the distribution differences, and the second hypothesis must propose a non-allelopathic mechanism (e.g. light quality and/or availability, differences in soil chemistry and/or physical characteristics, differences in leaf litter under different tree canopies, etc.). Students then spend about 3 weeks to collect and analyze their data, and present their results in an in-class symposium.

LAB OBJECTIVES:

At the conclusion of this multiweek lab, students will:

1. have a basic understanding of competitive interactions among members of a plant community and the ecological and evolutionary consequences of such interactions to plant community structure,
2. have designed and carried out experiments that are derived from two different, alternative hypotheses for the same observed, ecological pattern. They will gain experience evaluating their own methods, results, and conclusions in light of peer researcher's experiments. They will engage in oral and written communication about their scientific findings and discuss outcomes with peer researchers who have investigated yet different alternative hypotheses for the same pattern,

LAB OBJECTIVES (con.):

3. master identification of several native trees of eastern deciduous forest,
4. gain experience in the use of appropriate field and laboratory technology and instrumentation and will improve their ability to use computer software programs for statistics, graphics, and presentations,
5. gain further experience with scientific writing and with review and critique of primary scientific literature.

EQUIPMENT/ LOGISTICS REQUIRED:

- * measuring tapes, field guides, surveying flags, compasses,
- * soil sample test kits (pH, nitrates, phosphates, etc.),
- * canopy sunfleck ceptometer (for measuring light levels) and canopy spherical densiometer,
- * electronic balances,
- * blender,
- * seeds of beech, sugar maple, etc.,
- * greenhouse space devoted to course experiments and space in environmental chambers (light cycle, temperate and humidity controls),
- * institutional means of transportation to and from field sites.

SUMMARY OF WHAT IS DUE:

From this multiweek lab, students submit

- data from the first field lab (Q - do the densities of woody seedlings and/or saplings differ beneath Eastern Hemlock versus Sugar Maple or American Beech)?
- one-page report describing the statistical analysis and results of the first field lab,
- one-page research proposal,
- potential literature cited section, turned in one month prior to the written report due date, with a minimum of 12 primary literature citations,
- progress report (interview form, about 2 weeks before their final report is due),
- clearly labeled copies of original data,
- scientific lab report in the format of "Ecology" and composed according to the guidelines below,
- oral presentation during an in-class symposium,
- (optional) - written questions concerning the presentations of other groups,
- letter grade (A, B, C, D, F) of their choice for the lab activity and a brief written explanation of the grade given,

DESCRIPTION OF THE LAB ACTIVITY

INTRODUCTION (written for students):

Background

Some years ago, one of the faculty in the Biology Department noticed that fewer seedlings and saplings of broadleaved woody species seemed to grow beneath the canopies of Eastern Hemlock trees than beneath the canopies of other species on the Hope College Nature Preserve property. Since that time, a number of student projects have confirmed this pattern, but none have been successful in determining the mechanism by which Eastern Hemlocks inhibit the other species.

Procedure

During this week in lab, we will conduct a brief orientation walk on the property, during which you will observe the spatial distributions of seedlings and saplings relative to Eastern Hemlock trees. We will then collect data to address the question: "Are the densities of seedlings and saplings of woody broadleaved plants lower beneath the canopies of Eastern Hemlock (*Tsuga canadensis*) than beneath those of broadleaved trees?"

To address this question, each group of 3-4 students will sample seedlings and saplings beneath 3 Hemlock and 3 Sugar Maple canopies. So that the physical conditions and seed rain will be as similar as possible between the two canopy types, you should choose your Hemlocks at random (making sure that no other group has sampled them, of course), but choose your Maples such that they are the nearest canopy-level ones to each of the 3 Hemlocks. We will identify and count the seedlings and saplings within a 1 x 1 meter quadrat to the southwest of the trunk of each of the trees sampled. There's nothing special about that location, of course. In fact, that's the point: by choosing the site to sample before we even look at the trees, we reduce the possibility of biasing our results by choosing sample sites on the basis of their seedling density. So just use a compass to lay out each quadrat such that its northeast corner touches the tree trunk.

Within each quadrat, count the total number of seedlings/saplings of woody plants (beech, maple, hemlock, oak, shrubs, etc.) separately. Don't count herbaceous plants like grasses, forbs, mosses, etc. Use the data collected by all groups in your lab section to test the null hypothesis that the mean density of woody seedlings and saplings does not differ between Hemlocks and Sugar Maples. The alternative hypothesis in this case is directional: mean density of seedlings and saplings is higher beneath Hemlocks than beneath Sugar Maples. So you'll need to do a one-tailed t-test. Note that when you're doing a one-tailed test the alpha levels for statistical significance are half of those for two-tailed tests, for which the tables of critical values are written. To get the correct critical value of t for a one-tailed test at $\alpha = 0.05$, use the column for $\alpha = 0.10$.

Assuming that we find a difference in seedling/sapling density beneath hemlocks and maples in the first part, your group should discuss factors that might be responsible for it. After doing so, your group should propose to test two different working hypotheses to explain the difference. You're free (encouraged!) to come up with other hypotheses, of course, but a few that we can suggest include:

- * Light intensity is lower beneath Hemlock canopies, such that germination and/or growth of woody seedlings is inhibited.
- * The canopies of Hemlock trees act as "umbrellas" that shed seeds of broadleaved trees to the side, such that areas beneath Hemlock crowns receive fewer colonists.
- * Hemlocks alter soil pH in such a way that germination or growth of broadleaved plants are inhibited.
- * Hemlocks produce allelochemicals, which either leach from the stems or foliage or are exuded from the roots, and which inhibit either germination or growth, or both.

Each lab group will formally propose 2 different working hypotheses to investigate, one of which must deal with allelopathy (chemical inhibition via compounds produced by Hemlock; alteration of soil pH doesn't count here). Each group will work independently of the others, and write a 1-2 page proposal that:

- 1) Presents the statistical analysis and conclusion from the first part of the investigation (the analysis discussed above);
- 2) Poses two hypotheses about the mode of inhibition (e. g., what is it about Hemlock trees that results in lower densities of other plants near them), one of which deals with allelopathy. The other hypothesis can focus on another factor of your own choosing, assuming that your instructor approves it;
- 3) Briefly describes a series of experiments or other data collection procedures that you will use to test these hypotheses. Here again, be sure that you state explicitly what sorts of data you'll collect and how you'll analyze them, including statistical tests, etc;
- 4) Contains a brief list of materials that you will need to do your study. You can use space in the greenhouse, pH meters, PAR ceptometers (which are fancy light meters often used in photosynthesis labs), and just about anything else within reason.

Be aware that we can't realistically subject maple or other tree seeds from the forest to experiments you might think of to assess the effect of different pH's, soil extracts, etc., since this year's seeds won't germinate until next spring. Instead, if you plan a "bioassay," consider using seeds from a widely available and rapid germinating plant (such as sunflower, alfalfa, or lettuce - all of which are often used in these kinds of experiments).

The calendar of events for this study is as follows:

Week 1: Collect initial data and report to instructor, who will compile it for all lab sections and distribute it via the course website. Groups will include statistical analyses of initial data in their proposals.

Week 2: Proposals due, in lecture. Start collecting data as soon as your instructor has approved your proposal.

Week 4: progress report: you'll need to show your instructor your experiments if they're in the greenhouse, show her/him the data you have collected thus far, etc. Set up an appointment with your instructor that can be attended by as many of your group members as possible.

Week 8: Formal (individual) lab report due, in lecture.

Week 9: Group oral presentation of results using PowerPoint (more on this later), and written outline for the presentation (hard copy or electronic copy of the PowerPoint presentation preferred).

MATERIALS AND METHODS.

Study Site(s).

Study sites are located in the Hope College Biology Nature Preserve, which is a 50 acre parcel of beech-maple "dune" forest about 1-2 km from Lake Michigan.

Overview of Data Collection and Analysis Methods.

During the first lab in the field, students are instructed in the identification of the major tree species at the field site, including seedlings and saplings. Then they are asked to break up into small groups and to observe patterns in the distribution of those young plants with respect to the distribution of 3 of the dominant tree species : Eastern Hemlock, Sugar Maple, and American Beech.

As the instructor circulates to assess the progress of each group's observations, s/he encourages those groups that have noticed a difference (fewer seedlings and saplings beneath Eastern Hemlock, for example), to begin to record some preliminary observations/data documenting that difference. The students are asked to begin to think about how they would test such an hypothesis. After an hour, all groups convene to discuss their findings and their hypotheses. The instructor presents the question for the independent project investigation and the written, 1-2 page proposal as an assignment.

Guidelines for Research Proposals.

Students are asked to include the following information in their proposal:

- 1) A description of how they will test the hypothesis that woody plants of other species are distributed differently beneath hemlock trees than they are beneath other species of trees. They are asked to explicitly state what kind(s) of data they will collect, how they will do the data analysis, and the statistical tests they will use.
- 2) Assuming that the students do find evidence of inhibition, they are asked to pose at least two hypotheses about the mode of inhibition (e. g., what is it about Hemlock trees that results in lower densities of other plants near them). At least one of these hypotheses has to involve allelopathy (chemical inhibition via compounds produced by Eastern Hemlock). The other hypothesis can focus on another factor of the group's choosing, with instructor approval.
- 3) A description of a series of experiments or other data collection procedures that the group will use to test these hypotheses. Again, students are asked to state explicitly what sorts of data will be collected, how the data will be analyzed, including statistical tests.
- 4) A brief list of materials needed for the study.

QUESTIONS FOR FURTHER THOUGHT AND DISCUSSION.

- 1) Based on the group presentations, summarize what you think is the most likely explanation for the decreased abundance of woody saplings beneath Eastern Hemlock?
- 2) What criteria have you used for giving this particular hypothesis your greatest support?
- 3) Have the research investigations, on the whole, suggested additional explanations for the plant community pattern that were not initially considered? If so, what are they, and how could they be investigated?
- 4) Does support for one hypothesis necessarily negate other hypotheses? Give an example of a case in which evidence for two or more hypotheses are or are not mutually exclusive. Could you design an experiment in which the hypotheses ARE mutually exclusive? Briefly, describe the design of such an experiment.
- 5) What selective advantages are associated with a plant's ability to inhibit competing plants of a different species? Offer other examples from different plant communities where similar inhibition processes occur, and explain the mechanisms of inhibition that are used in your examples.
- 6) If inhibition helps increase a plant's fitness, why do we not find evidence that all plants are doing it? For example, why don't we see similar patterns for American Beech or for Sugar Maple at the biology field station?
- 7) How does competition among plant species at this forest site contribute to the structure of the plant community there?

POTENTIALLY USEFUL REFERENCES FOR THE HEMLOCK PROJECT.

- Asakawa, C., and D. M. M. Dakshini. 1999. Allelopathic potential of *Verbesina encelioides* root leachate in soil. Canadian Journal of Botany 77: 1419-1424.
- Beatty, S. W. 1984. Influence of microtopography and canopy species on spatial patterns of forest understory plants. Ecology 65: 1406-1419.
- Barrett, J. W. 1962. Regional silviculture of the United States. Ronald Press, New York, New York, USA.
- Bond, B. J., B. T. Farnsworth, R. A. Coulombe, and W. E. Winner. 1999. Foliage physiology and biochemistry in response to light gradients in conifers with varying shade tolerance. Oecologia 120: 183-192.
- Canham, C. D., A. C. Finzi, S. W. Pacala, and D. H. Burbank. 1994. Causes and consequences of resource heterogeneity in forests: interspecific variation in light transmission by canopy trees. Canadian Journal of Forest Research 24: 337-349.
- Catovsky, S., and F. A. Bazzaz. 2000. The role of resource interactions and seedling regeneration in maintaining a positive feedback in hemlock stands. Journal of Ecology 88: 100-112.
- Collins, S. L. 1990. Habitat relationships and survivorship of tree seedlings in hemlock-hardwood forest. Canadian Journal of Botany 68: 790-797.
- Daubenmire, R. F. 1930. The relation of certain ecological factors to the inhibition of forest floor herbs under hemlock. Butler University Botanical Studies 1: 61-76.
- Davies, S. J. 1998. Photosynthesis of nine pioneer *Macaranga* species from Borneo in relation to life history. Ecology 79: 2292-2308.
- Davis, G., and A. Hart. 1961. Effect of seedbed preparation on natural reproduction of spruce and hemlock under dense shade. U.S. Department of Agriculture Forest Service, Northeast Forest Experiment Station Paper 160.
- Davis, M. B. 1987. Invasions of forest communities during the Holocene: beech and hemlock in the Great Lakes Region. Pages 373-393 in A. J. Gray, M. J. Crawley, and P. J. Edwards, editors. Colonization, succession and stability. Blackwell Scientific, Oxford, England.
- Davis, M. B., K. D. Woods, S. L. Webb, and R. P. Futyma. 1986. Dispersal versus climate: expansion of *Fagus* and *Tsuga* into the Upper Great Lakes. Vegetatio 67: 93-103.
- Fowells, H. A. 1965. Silvics of the forest trees of the United States. U.S. Department of Agriculture, Forest Service, Agriculture Handbook Number 271.
- Frelich, L. E. 1986. Natural disturbance frequencies in the hemlock-hardwood forests of the Upper Great Lakes Region. Dissertation. University of Wisconsin-Madison, Madison, Wisconsin, USA.
- Frelich, L. E., and C. G. Lorimer. 1991. Natural disturbance regimes in hemlock-hardwood forest of the Upper Great Lakes Region. Ecological Monographs 61: 145-164.
- Frelich, L. E., R. R. Calcote, M. B. Davis, and J. Pastor. 1993. Patch formation and maintenance in an old-growth Hemlock-Hardwood forest. Ecology 74: 513-527.

- Goder, H. A. 1955. A phytosociological study of *Tsuga canadensis* near the termination of its range in Wisconsin. Dissertation. University of Wisconsin-Madison, Madison, Wisconsin, USA.
- Graham, S. A. 1941. The question of hemlock establishment. Journal of Forestry 39: 567-569.
- Jenkins, J.C., J. D. Aber, and C. D. Canham. 1999. Hemlock wooly adelgid impacts on community structure and nitrogen cycling rates in Eastern Hemlock forests. Canadian Journal of Forest Research 29: 630-645.
- Leebens-Mack, J. H. 1989. Spatial patterns in seed rain density and seedling recruitment of northern mixed hardwood species in Sylvania Wilderness Area, Michigan. Thesis. University of Minnesota, Minneapolis, Minnesota, USA.
- Lorimer, C. G. 1983. Eighty-year development of northern red oak after partial cutting in a mixed-species Wisconsin forest. Forest Science 29: 371-383.
- Lorimer, C. G., and L. E. Frelich. 1989. A methodology for estimating canopy disturbance frequency and intensity in dense temperate forests. Canadian Journal of Forest Research 19: 651-663.
- Mladenoff, D. J. 1987. Dynamics of nitrogen mineralization and nitrification in hemlock and hardwood treefall gaps. Ecology 68: 1171-1180.
- Nilsen, E. T., J. F. Walker, O. K. Miller, S. W. Semones, T. T. Lei, and B. D. Clinton. 1999. Inhibition of seedling survival under *Rhododendron maximum* (Ericaceae): could allelopathy be a cause? American Journal of Botany 11: 1597-1605.
- Pastor, J., and M. Broschart. 1990. The special pattern of a northern conifer-hardwood landscape. Landscape Ecology 4: 55-68.
- Runkle, J. R. 1981. Gap regeneration in some old-growth forests of the eastern United States. Ecology 62: 1041-1051.
- Runkle, J. R. 1982. Patterns of disturbance in some old growth mesic forests of the eastern North America. Ecology 63: 1533-1546
- Sipe, T. W., and F. A. Bazzaz. 1995. Gap partitioning among Maples (*Acer*) in Central New England: survival and growth. Ecology 76: 1587.
- Ward, H. A., and L. H. McCormick. 1982. Eastern Hemlock allelopathy. Forest Science 28: 681-686.
- Woods, K. D., and R. H. Whittaker. 1981. Canopy-understory interaction and the internal dynamics of mature hardwood and hemlock hardwood forests. Pages 305-323 in D.C. West, H.H. Shugart, and D.B. Botkin, editors. Forest succession, concepts and applications. Springer-Verlag, New York, New York, USA.
- Woods, K. D. 2000. Dynamics in late-successional hemlock-hardwood forests over three decades. Ecology 81: 110-126.
- Woods, K. D. 2000. Long-term change and spatial pattern in a late-successional hemlock-northern hardwood forest. Journal of Ecology 88: 267-282.
- York, T. E., D. J. Leopold, and D. J. Raynal. 2000. Vascular plant propagule banks of six eastern hemlock stands in the Catskill Mountains of New York. Journal of the Torrey Botanical Society 127: 87-93.

Comments by Contributing Authors – Greg Murray and Kathy Winnett-Murray

CHALLENGES TO ANTICIPATE AND SOLVE.

We have identified several challenges that commonly arise:

1. the experiments carried out by each team may involve different techniques or approaches aimed at answering similar questions. Because of differences among groups in experimental focus and design, differences sometimes also arise in results and data interpretation. Students are encouraged to critically evaluate their own work and that of other teams. They will learn, through doing this experiment, that the way they set up their experimental design in the first place, has everything in the world to do with what they find out. Consistently, we find that students need to gain experience in understanding the difference between “thinking” they know what they are testing when they design an experiment, and actually “knowing” what they have tested. This invariably comes with hindsight, but that’s an integral part of the learning experience in this lab.
2. we don’t give the references to the students in the student handout, since that is one of the things we require from them as part of the grading.

COMMENTS ON THE LAB DESCRIPTION.

Introducing the Lab to Your Students.

First, we take our students to the field site, identify 4 or 5 species of trees, including the ones most pertinent to the upcoming investigation, give a little bit of information on history of the site, and then ask them to walk around in pairs and look at the woody seedlings and saplings in the understory. We ask them to notice particular density patterns, if any. Typically, at our site, students will notice patterns derived from light gaps, terrain, soil moisture, and very obviously...a relative paucity of seedlings and saplings in distinct “circles” emanating from around Eastern Hemlock trees!

Then, we stand or sit in the forest and talk about what some of these patterns are, and how we would TEST for a hypothesized pattern, focusing on the hemlock pattern: Is the density of woody seedlings and/or saplings beneath Eastern Hemlock canopies lower than under the adjacent canopies of other common species in this forest, such as American Beech and Sugar Maple? We ASK the students HOW they can investigate this (in the next hour!). As a group, we discuss alternative suggestions from students themselves, followed up a consensus on what seems to be the best approach. For example, students need to decide on which plants to sample, (seedlings, saplings, dbh criteria, height criteria)? for what area around each tree? What constitutes a sample? A replicate? What constitutes a paired observation (non-Hemlock canopy)?

Possible exclusions (e.g. dead trees, trail influences)? We spend perhaps 30 min. deriving a quick, but consistent means of acquiring our first data set, and then students set out in pairs to collect this information. It is this data set that forms the basis of independently derived inhibition hypotheses for the independent project portion of the lab.

Comments On the Activities in the Lab.

This is a field and laboratory project that we use during September - November in southwest Michigan. As a guided inquiry (instructor chooses problem, but students are expected to design methods of tackling the problem) it has been very appropriate for sophomore-and-up undergraduates who are ready to begin instructor-facilitated independent investigations. Students are introduced to the concepts of perception and scale while exploring the potential allelopathic interactions that take place within a temporal or spatial framework with which they have little previous familiarity. They gain experience in articulating their own hypotheses and alternative hypotheses, designing well-controlled experiments, identifying dependent, independent and controlled variables, and choosing appropriate sample sizes and treatments. Because all teams investigate the same general questions (Do hemlocks inhibit the establishment of other wood plant species, and if so what are the mechanisms?) but from different approaches (soil chemistry vs. germination rates vs. plant distribution patterns), students also gain experience in the critical evaluation of their work and that of others.

We first came up with the idea for this project when we observed distinctive patterns of establishment (or lack of establishment) of broadleaved tree seedlings beneath Eastern Hemlock trees as compared with that beneath other species (e.g. Sugar Maple, American Beech) in the same forest. Encouraging our students to make observations that will allow them to discover the same patterns has become the introduction to the "lab". Once the patterns seem evident, students are challenged to gather evidence to support or refute this hypothesis, and then to follow up with experiments that will help elucidate the underlying reasons for the observed differences in seedling establishment. There is a wealth of primary literature available on the topic (including potential mechanisms for allelopathy), and thus a good area to use to instruct students in literature-searching skills and the value of integrating other research results with their own.

Visit easily accessible field sites, preferably forests that have been minimally disturbed over the past few decades, and examine the understories for the same kind of evidence of inhibitory effects that we observed at our site. If Eastern Hemlock does not occur in your area, find out what local tree species are known to exert inhibitory effects on other plants (e.g. Ailanthus), and then determine a nearby site where those trees are part of the community. That's all you really need!

An excerpt from the assignment sheet follows:

- 18 September - Field trip and preliminary observations at the study site (3 hrs. includes 25 mins transport time each way, 1 hr to collect preliminary data on seedlings distributions, 1 hr for discussion and overview of the project assignment.

- 25 September - Written proposals from each team of 4 students are due. Students may start collecting data when the proposal is approved by the instructor.

- 21 October - Written progress report. Instructor meets briefly with each group to view experiments set up in the greenhouse, raw data collected thus far, discuss statistical analysis, etc.

- 2 December - Group oral presentations occur during a 3 hr lab slot (about 15 minutes/group). We have a one-page grade-sheet that is distributed to the students well in advance of the oral presentation so that students will know exactly what is expected.

When do the students work on their projects? Typically, we allow the time from at least 1 additional 3 hr lab to work on projects, but most teams devote more than this on their own. Often, if additional labs have been canceled because of poor weather, we designate that as "time to work on group projects" as well.

COMMENTS ON THE QUESTIONS FOR FURTHER THOUGHT.

General Comment. This lab could be a good connection for lecture coverage of interspecific competition in an ecology or evolution course. From this familiar starting point (students have now seen evidence of competition among species in a self-designed investigation), build concepts such as competitive exclusion, species interactions, invasive species and biodiversity, coexistence of competing species, resource partitioning, and the role of competition in structuring communities.

ASSESSMENT OF STUDENT LEARNING OUTCOMES.

Each team receives a grade for the proposal, for the progress meeting, and for the oral presentation. A minimum of 5 primary literature citations are required as a supplementary handout for the oral presentation.

We use a basic Grade Sheet for scoring their Lab Reports (available at HemlockGradeSheet.pdf). We give this page to the students in Week 1.

In addition to the oral and written reports, students in this course have 2 laboratory practicals each semester. During the lab practicals, students are asked to DO various tasks that derive from the course experiments, including the hemlock lab. For example, students are given a sample data set, and asked to complete a paired-samples t-test using SYSTAT, on the computer. Construction of computer graphics are graded similarly. Other items on lab practicals derived from this lab include: plant identification, use of light ceptometers, measuring devices, a portable photosynthetic system, and evaluation of various hypotheses using hypothetical data sets and results.

Comments On the Assessment of Student Learning Outcomes:

We try to stagger graded events to help students learn valuable skills in time management of large tasks (e.g. progress interview, up-front literature cited list, etc.).

In some semesters, we provide students with a re-write option for the written report. However, to keep students from making the first submission a "rough draft" (and consequently placing the burden of editing on us), we do not call it a draft - it is the first submission of the final paper and is worth 75 points. Students who elect to re-submit can only earn UP TO an additional 25 pts. For students who do NOT re-submit, the original grade is pro-rated to an equivalent score out of 100 possible.

Peer review can be incorporated easily into the oral presentations. One mechanism we have used to evaluate peer review is to have students write their questions that they ask other groups, submit those to us, and then we grade the quality of those questions. In one semester, we asked all groups to grade each other, using the same rubric sheet that the instructor's used. We think this is a good exercise, but in our case, found that students tend to be exceptionally lenient in grading oral presentations, so we have not actually used the student scores as a part of the final grade since then.

FORMATIVE EVALUATION OF THIS EXPERIMENT.

Tools for Formative Evaluation of this Experiment:

At the end of the semester, students are asked to give each lab investigation a letter grade (A, B, C, D or F) and a brief explanation of why that grade was given. We use this feedback from the students to determine which labs should be retained, improved, modified (e.g. extended, shortened, more time on statistics, new field site, etc.), or simply “tossed” in preparation for the next year’s class.

Comments On the Evaluation of the Lab Activity:

The greatest value to us comes in knowing WHY students enjoyed or hated a particular lab. The hemlock lab is consistently rated highly because: (a) it gives students a great deal of independence and a sense of personal ownership and accomplishment, and (b) it gives students an opportunity to spend lots of time outdoors in the forest, and the vast majority of them really appreciate this. .

In addition, extensive notes on how to conduct formative evaluation are in the Teaching Resources sector of TIEE under the keyword "Formative Evaluation."

TRANSLATING THE ACTIVITY TO OTHER SCALES.

This investigation could be modified as a more structured class project to fit into 1 or 2 lab periods (all students do the same investigation, or groups work on assigned sub-topics); it can also be used with a different “focal” tree species other than Eastern Hemlock.

To adapt this investigation for larger institutions (100 or more students involved), we would suggest the following modification, intended to provide a more manageable structure. Normally, with larger classes there are multiple lab sections meeting more than one day of the week. Instead of allowing every student group to come up with their own independent experiments, link particular experiments across 2 or 3 different lab groups that meet on different days of the week (e.g. a Monday and a Tuesday group will work on soil pH; a Monday and a Tuesday group will work on the light environment, etc.). Allow small amounts of time during lecture (2 or 3 times during the course of the project should be sufficient), when all students are together, for counterpart teams (the Monday and Tuesday groups working on the same experiment) to meet, share notes, agree on protocols, etc. This will double the amount of data that is generated for each experiment, while still encouraging full participation by all members of all groups because the working group size, per se, is not changed (Monday teams collect data on Mondays and Tuesday teams collect data on Tuesdays, etc.). Having teams double-up on experiments, however, creates a much smaller drain on the amount and variety of resources that will be used, and the number of different experiments that the instructor must supervise. Another benefit of this approach comes in the experience that counterpart groups will gain in collaborating with each other by discussing protocols that are acceptable to both teams, coordinating work schedules, maintaining consistency in measurement techniques, interpreting results, etc.

For high school students, or other classes in which the students have had less preparation in designing their own experiments, we suggest that the instructor add more structure to the experimental portion. That is, the instructor may want to create a list of possible questions to investigate, and allow student groups to select from that list. In this way, the students still have a choice in what question topic may interest them the most, but the instructor will determine the relevant questions and the level of ambition and experimental rigor required to answer them.

For institutions with little or no access to forested sites, consider a similar investigation on the impact of invasive plant species on the growth and distribution of native plants in a more disturbed plant community (regenerating farmland, overgrown fields, etc.). Possibilities for focal invasive plant species might include Autumn Olive (*Eleagnus umbellata*), Tree of Heaven (*Ailanthus* spp.), Myrtle (*Vinca minor*), or Purple Loosestrife (*Lythrum salicaria*).

CREDITS AND DISCLAIMERS

CREDITS FOR THIS EXPERIMENT:

We first came up with the idea for this project when we observed distinctive patterns of establishment (or lack of establishment) of broadleaved tree seedlings beneath Eastern Hemlock trees as compared with that beneath other species (e.g. Sugar Maple, American Beech) in the same forest. Encouraging our students to make observations that will allow them to discover the same patterns has become the introduction to the "lab". Once the patterns seem evident, students are challenged to gather evidence to support or refute this hypothesis, and then to follow up with experiments that will help elucidate the underlying reasons for the observed differences in seedling establishment. We are greatly indebted to our former graduate school instructors, Drs. Peter Feinsinger, Jim Dole, Martha Crump, Jack Kaufmann, Jane Brockman, and Archie Carr for modeling exactly this kind of guided inquiry (stimulated by an initial, intriguing observation) to us in the graduate courses we took from them, long before anyone was calling it by that name.

This submission was greatly improved by comments from anonymous reviewers.

GENERIC DISCLAIMER:

Adult supervision is recommended when performing this lab activity. We also recommend that common sense and proper safety precautions be followed by all participants. No responsibility is implied or taken by the contributing author, the editors of this Volume, nor anyone associated with maintaining the TIEE web site, nor by their academic employers, nor by the Ecological Society of America for anyone who sustains injuries as a result of using the materials or ideas, or performing the procedures put forth at the TIEE web site or in any printed materials that derive therefrom.

The Ecological Society of America (ESA) holds the copyright for TIEE Volume 1, and the authors retain the copyright for the content of individual contributions (although some figure and data sets may bear further copyright notice). No part of this publication may be reproduced, stored in a retrieval system, or transmitted, in any form or by any means, electronic, mechanical, photocopying, recording, or otherwise, without the prior written permission of the copyright owner. Use solely at one's own institution with no intent for profit is excluded from the preceding copyright restriction, unless otherwise noted. Proper credit to this publication must be included in your lecture or laboratory outline/ course handout for each use.

To reiterate, you are welcome to download some or all of the material posted at this site for your use in your course(s), which does not include commercial uses for profit. Also, please be aware of the legal restrictions on copyright use for published materials posted at this site. We have obtained permission to use all copyrighted materials, data, figures, tables, images, etc. posted at this site solely for the uses described in the TIEE site.

Lastly, we request that you return your students' and your comments on this activity to Susan Musante (smusante@aol.com), Managing Editor for TIEE, for posting at this site.