Title
When Biocontrol Isn't Effective: Making Predictions and Understanding Consequences

ABSTRACT PAGE

The Issue
Invasive species cause significant ecological and economic harm, and therefore effective management strategies are of utmost importance. One common yet controversial method proposed to control invasive plant species is biological control. This issue explores how relatively short-term ecological research can be combined with matrix modeling to evaluate the likely success of biological control. Students will incorporate actual research data into a modeling program to determine the effects of biocontrol on the population growth rate of an invasive species. Further, they will explore the consequences of introducing an actual biological control agent and discuss the associated risks and benefits. This issue, particularly Figure Set 2, is most appropriate for use in an upper-level ecology or population ecology course.

Ecological Content
biological control, demography, herbivory, indirect effects, invasive species, matrix modeling, population ecology, plant tolerance, trophic cascades

Student-active Approaches
think-pair-share, jigsaw

Student Assessments
essay quiz, one minute paper, concept map

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Acknowledgements
The authors would like to thank E.A. Pardini and the students in the Population Ecology course at Washington University in St. Louis for encouraging the continued development of this activity and Washington University and the National Research Initiative of the USDA Cooperative State Research, Education and Extension Service, grant number #05-2290, for financial support.

Citation
Schutzenhofer, M. R. and T. M. Knight. February 2009, posting date. When Biocontrol Isn't Effective: Making Predictions and Understanding Consequences. *Teaching Issues and Experiments in Ecology*, Vol. 6: Issues Figure Set #1 [online].
http://tiee.ecoed.net/vol/v6/issues/figure_sets/biocontrol /abstract.html

Cover Image
Cover Image.jpg

Cover Image Caption
The invasive plant, *Lespedeza cuneata*. Photo credit: Michele Schutzenhofer

OVERVIEW PAGE

What Is the Ecological Issue?

Invasive species are a major threat to global biodiversity (ESA 2000; Davis 2003; Gurevitch and Padilla 2004), second only to habitat destruction. Invasive species have rapid rates of population growth, and displace native species from the habitat. One solution to the invasive plant species problem is biological control. In plants, for instance, biological control consists of introducing enemies (e.g., herbivores) from the plant's native range. The herbivores are meant to "damage" the invasive plant species by consuming plant tissue, reducing plant resources, and therefore curbing its population growth. Sometimes biological control is successful, and sometimes it is not (Messing and Wright 2006). Thus, it is critical for ecologists to predict the likely success of biological control, and how much damage the control agent must inflict on an invasive species in order to significantly reduce its rate of population growth.

Population ecologists often use demographic matrix models to project the growth rate of a population (Horn 1975, van Groenendael et al., 1988; Akcakaya et al., 1999; Caswell 2000; Morris and Doak, 2002). Demographic matrix models are particularly useful for plants and animals that are easily classified into stage and size classes. Many organisms fit this criteria. For example, trees can be classified into seeds, seedlings, saplings and adults. Many insects can be classified based on their number of molts. Amphibians can be classified into eggs, tadpoles and adults.

Demographic matrix models use detailed information about growth, survivorship and fertility of organisms to project the growth rate of the population. These models are especially useful for invasive plants, because we can project how fast the population is growing, and examine how different management techniques will curb this growth. The input parameters of matrix models are vital rates (survivorship, growth, fertility) of individuals in each stage class (e.g., in plants, stage classes often include seedlings, juveniles and adults) in a population. The output of these models is the growth rate of the population. If the growth rate of the population (λ) is 1, then the population is expected to stay the same size through time. If $\lambda>1$, then the population will grow exponentially. If $\lambda<1$, the population will decline towards extinction.

Reducing the population growth rate of an invasive plant might be achieved through management. Once a demographic matrix model is created, this model can be used to inform managers which stage classes they should focus their management on in order to cause the most dramatic decrease in the growth rate of the population. The stage-specific vital rates contribute unequally to population growth rate; changes in some vital rates will have large effects on population growth rate, while others have relatively small effects. Elasticity analysis can be conducted to determine how changes in each vital rate will affect population growth rate. Elasticity analysis is a type of perturbation analysis that is achieved by making small changes in each vital rate and quantifying how such changes affect the population growth rate.

The goal of biocontrol is to cause a rapidly growing invasive population (i.e., $\lambda>1$) to either stabilize ($\lambda=1$) or decline towards extinction ($\lambda<1$). In order to evaluate the likely success of biological control, researchers can damage (remove leaf tissue manually) invasive species in a manner similar to that of a biocontrol agent, and measure the effects of that damage on vital rates. Matrix models in the presence and absence of damage can be compared to see if the damage inflicted will curb the population growth rate of the invasive species.

Further, even if biological control is predicted to be a feasible option, it is still considered a risky management strategy, as the control agents may have unexpected and negative effects on native species (Louda *et al* 2003). Typically, such negative effects are instances of host-switching, where the introduced control agent not only damages the invasive target species, but also native species (Messing and Wright 2006). A moth, *Cactoblastis cactorum*, for example, was introduced to the United States to control an invasive prickly pear cactus, but resulted in attack on many native cacti (Louda *et al* 2003). Furthermore, plants and herbivores are not the only members of an ecological community; there are also predators of herbivores, carnivores, parasites, etc. Therefore, it is essential to examine all trophic interactions, including those beyond the species of interest, to fully understand which interactions might produce unexpected effects following an introduction of an herbivorous biocontrol agent into a community (Pearson and Callaway 2006).

In this issue students can build on interpreting graphs and teaching each other, to exploring how matrix models are used to predict potential effectiveness of biological control using an example from the literature. This exercise allows them to integrate research data into a computer program (R, which is freely available on the internet, http://cran.r-project.org/bin/windows/base/), hypothesize about and interpret their results, teach other students, and understand the application of the research. Further, they will learn about how trophic cascades can result in unintended consequences when scientists and communities decide to go forward with introducing biological control agents.

References

- Akcakaya, H.R., M. A. Burgman, and L. R. Ginzburg. 1999. *Applied Population Ecology: principles and computer exercises using RAMAS EcoLab 2.0*, 2nd Edition. Sinauer Associates, Sunderland.

- Caswell, H. 2001. *Matrix Population Models: Construction, analysis, and interpretation*. 2nd edition. Sinauer Associates, Inc. Sunderland, Massachusetts, U.S.A.

- Davis, M.A. 2003. Biotic globalization: Does competition from introduced species threaten biodiversity? *Bioscience* **53**: 481-489.

- Ecological Society of America. 2000. Biotic Invasions: Causes, Epidemiology, Global Consequences and Control. *Issues in Ecology*. http://www.esa.org/science_resources/issues/FileEnglish/issue5.pdf

- Gurevitch, J. and Padilla, D.K. 2004. Are invasive species a major cause of extinctions? *Trends in Ecology and the Environment* **19**: 470-474.

- Horn, H.S., 1975. Markovian processes of forest succession. In: M.L., Cody & J.M., Diamond (eds) *Ecology and Evolution of Communities*. Belknap, Harvard.

- Louda, S.M., Pemberton, R.W., Johnson, M.T., and Follett, P.A. 2003. Nontarget effects: the Achilles' heel of biological control? Retrospective analyses to reduce risk associated with biocontrol introductions. *Annual Review of Entomology* **48**: 365-396.

- Messing, R.H. and Wright, M.G. 2006 Biological control of invasive species: solution or pollution? *Frontiers in Ecology and the Environment* **4**: 132-140.

- Morris, W.F. and D.F. Doak. 2002. *Quantitative conservation biology: Theory and practice of population viability analysis*. Sinauer Associates, Sunderland.

- Pearson, D.E. and Callaway, R.M. 2003. Indirect Effects of host-specific biological control agents. *Trends in Ecology and Evolution* **18**:456-461.

- Schutzenhofer, M.R. and Knight, T.M. 2007. Population-level effects of augmented herbivory on *Lespedeza cuneata*: Implications for biological control. *Ecological Applications* **17**: 965-971.

- Thomas, M.B. and Reid, A.M. 2007. Are exotic natural enemies an effective way of controlling invasive plants? *Trends in Ecology and Evolution* **22**: 447-453.

- van Groenendael J. M., H. de Kroon, and H. Caswell. 1988. Projection matrices in population biology. *Trends in Ecology and Evolution* **3**:264-269.

- Wajnberg, E., Scott, J.K., and Quimby, P.C., editors. 2001. *Evaluating indirect ecological effects of biological control*. CABI Publishing, Wallingford, Oxon, UK.

FIGURE SETS PAGE

These are published figures from peer-reviewed research journals and monographs that engage students in data analysis and critical thinking organized by teaching approach, Bloom's Taxonomy cognitive skills, and class size. The student-active approaches listed here are suggestions and examples; modify them as appropriate for your teaching. The class size and time requited designations are relative ones and indicate approximate categories.

Figure Set and Ecological Question	**Student-active Approach**	**Cognitive Skill**	**Class Size/Time**
1: What are the effects of herbivory on individual plant survival and growth? (Schutzenhofer and Knight 2007)	Think-pair-share	Knowledge, Comprehension	Small-Short
2: What are the effects of herbivory on population growth rate? And, which vital rates have the potential to cause the largest change in the population growth rate? (Schutzenhofer and Knight 2007)	Think-pair-share	Knowledge, Comprehension, Interpretation	Small/Moderate -Long
3: Indirect effects of biological control of knapweed. (Pearson et al. 2000, Pearson and Callaway 2006)	Jigsaw	Comprehension, Interpretation, Synthesis	Small-Medium/Moderate-Long

Resources

- Site to download R program
http://cran.r-project.org/bin/windows/base/

- Biological control information page
http://cipm.ncsu.edu/ent/biocontrol/

- Pages with fact sheets on *Lespedeza cuneata*
http://tncweeds.ucdavis.edu/esadocs/lespcune.html
http://www.nps.gov/plants/alien/fact/lecu1.htm
http://plants.usda.gov/java/profile?symbol=LECU
http://www.fs.fed.us/database/feis/plants/forb/lescun/all.html

- Biology and biological control information on knapweed
http://www.invasive.org/weeds/knapweed/

- Site with audio files about knapweed
http://www.invasiveweeds.com/canido/management/spottedknapweed.html

Student Handouts:

- Handout 1: A) How values from a life cycle graph go into a matrix and B) Putting Transition Probabilities into a Matrix DOC
- Handout 2: Instructions for using the *R* Program 'Lespedeza' to calculate population growth rate (λ) DOC
- Handout 3: A Population Growth Rate of the Invasive *Lespedeza cuneata*
  DOC
- Handout 4: A) Instructions for Changing Data in *R* Program
  DOC
- Handout 5: Population Growth Rates of the Invasive *Lespedeza cuneata* in different clipping treatments
  DOC
- Handout 6: Elasticity Analysis of Population Growth Rate of the Invasive *Lespedeza cuneata*
  DOC