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Fire, Soil, Native Species and Control of *Phalaris arundinacea* in a Wetland Recovery Project.

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Fire, Soil, Native Species, and Control of *Phalaris arundinacea* in a Wetland Recovery Project

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by

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ABSTRACT

Fire, Soil, Native Species, and Control *of Phalaris arundinacea* in a Wetland Recovery Project

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Southern Appalachian *Phalaris arundinacea* control was investigated by: 1) correlating cover and species richness with soil characteristics across transects; 2) burning and herbicide use to determine conditions facilitating native plant establishment; and 3) hemi-parasitic *Pedicularis lanceolata* tested as a biological control.

Phalaris cover was correlated with subsoil consolidation; areas without *Phalaris* had consolidated subsoil while *Phalaris* at >50% cover established on loose soil. *Phalaris* cover inhibited species richness (r^2=0.78). No soil characteristic predicted species richness.

Herbicide reduced *Phalaris* cover and aerial biomass by 23% and 63% respectively, compared to controls. Burning was ineffective. Two summers after herbicide *Phalaris* subterranean biomass remained 32% less than control biomass. Monocot transplants established readily following herbicide but dicot transplants were less likely to survive.

Pedicularis parasitized *Phalaris*. *Pedicularis*' effect on a mixed species total (r^2=0.735) was non-linear; implying greater effect on large plants. Non-parasitic native plant species competition reduced biomass of *Phalaris* by 40%.

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CHAPTER 1

INTRODUCTION

Species richness in an Appalachian Tennessee wetland preserve was compromised by monocultures of an aggressive, invasive species (reed canary grass, *Phalaris arundinacea*). An investigation of local site conditions affecting growth of *P. arundinacea* was used to examine ecological conditions leading to establishment of the species' monocultures and its interactions with native plants, routine control methods, and a potential biological control.

Background

Phalaris arundinacea

Phalaris arundinacea L. (Poaceae)[1] is an aggressive, cool-season wetland grass planted for erosion control and pasture. The species is native to both North America and Europe and tends to grow in fertile riparian zones. European agricultural strains and hybrids are notorious for their ability to overwhelm wetlands by rapidly growing dense foliage. Culms reach heights of two meters (Šrůtek 1993; Galatowitsch, Anderson, and Ascher 1999). Its cover interferes with wetland restorations by severely limiting the return of native species richness (Galatowitsch and others 1999; Morrison and Molofsky 1999). In Shady Valley's Orchard Bog area *P. arundinacea* grows in monocultures. Most of its stalks are infertile and topple after reaching ~ 1 m height, forming a dense blanket over the ground[2]. Wheeler (1995) points out that diverse plant cover is necessary to support diverse wildlife, so animal diversity cannot be expected to recover in *P. arundinacea* monocultures. *P. arundinacea* is not dominant under woodland conditions (Paine and Ribic 2002) and herbaceous canopies can form tighter

[1] Nomenclature in this paper follows Gleason and Cronquist (1991) except in the case of recent taxonomic changes, in which case the draft manuscript flora of Weakley (1998) was used.

canopies than trees (Marrs 1993), a condition both describing *P. arundinacea* and a potentially useful trait in its competitors.

The Orchard Bog Project

Shady Valley, in the mountainous northeast corner of Tennessee, has long been considered a unique area of habitat. It originally had fen, wooded fen, and wet forest habitats along tributaries of upper Beaverdam Creek (Barclay 1957). Drainage converted the valley floor to pasture and tree farming in the late 1960s, generally eliminating the wetlands. Orchard Bog is a remaining fragment of wetland habitat on the valley floor near Beaverdam Creek. Despite its name, Orchard Bog is a fen.

The Tennessee Chapter of The Nature Conservancy purchased Orchard Bog and some adjacent agricultural land as a preserve. By 1997 it had begun to restore water levels by blocking and backfilling ditches (Wetzel 2001). Rewetting of the drained part of the preserve had the unintended consequence of producing monotypic stands of *Phalaris arundinacea*, which covers approximately 60% of wetlands in the Orchard Bog preserve, causing low plant diversity and impaired species richness. Orchard Bog preserve areas without *P. arundinacea* are colonized by native pioneer species, including mosses and an assortment of small sedges, a cover type characteristic of biologically diverse fens (Grootjans and van Diggelen 1995).

Fen Habitat

Fens are wetlands fed by groundwater sources that keep the water table close to the soil surface (Mitsch and Gosselink 1993; Amon, Thompson, Carpenter, and Miner 2002). They are important habitat refuges for rare and regionally endemic plant and animal species in the southern Appalachians (Weakley and Schafale 1994). Fen ecosystems and the species in them are vulnerable to anthropogenic damage and

[2] Fertile stalks [culms] may remain standing until the next growing season.

degradation. Recovery from agricultural use after drainage, fertilization, and cultivated crops is slow and difficult for fens (Grootjans and van Diggelen 1995; Patzelt, Wild, and Pfadenhauer 2001).

Research Questions

This project investigates methods for increasing native species richness in areas currently occupied by *Phalaris arundinacea*. This project approaches restoration of native cover in the Orchard Bog preserve in three ways:

Soil Conditions and *Phalaris arundinacea*

It may be possible to control *Phalaris arundinacea* cover by manipulating soil conditions. *Phalaris arundinacea* cover varies within the Orchard Bog wetland recovery area and appears to be correlated with soil conditions. Moyle (1945) recognized soil qualities as important for the species. Morrison and Molofsky (1998) concluded that plot conditions are crucial to *P. arundinacea* establishment and suggested that soil properties were factors. Van Duren, Strykstra, Grootjans, ter Heerdt, and Pegtel (1998) gave an example of *P. arundinacea* being unable to grow on subsoil. Preliminary investigation showed that areas of the preserve with a majority of native plant cover and little or no *P. arundinacea* appeared to have shallow or recently exposed subsoil. To test the hypothesis that subsoil characteristics influenced *P. arundinacea* cover, soil conditions were tested and correlated with cover on transects crossing areas of both *P. arundinacea* abundance and areas of its absence. .

Native Plant Establishment in *Phalaris arundinacea*

Phalaris arundinacea spread using conditions that suited its habits but not those of desired species, invading after forest clearing, wetland drainage, and agricultural activity. Now, its monocultures resist reestablishment of native plant species by limiting

light levels at the soil surface. This shift of species composition corresponds to Johnstone's (1986) "invasion window" concept, which illustrates how environmental and biotic conditions affect plant establishment, including invasion by exotic and aggressive species. The goal of this native plant establishment part of the project was to create "invasion windows" for native species in *P. arundinacea* monocultures using fire, herbicide, and transplanting. Monocultures of *P. arundinacea* in experimental plots were treated with controlled burns or the herbicide Rodeo to determine subsequent success and establishment of transplants. The effect of herbicide on *P. arundinacea* is generally temporary (Apfelbaum and Sams 1987; Kilbride and Paveglio 1999) but in combination with other methods it can be effective for native species establishment (Pizzo and Schroeder 2001). The Nature Conservancy has been using controlled burns on *P. arundinacea* in the Orchard Bog preserve, but the effect has not been investigated; early-season burns have been ineffective for control for *P. arundinacea* (Apfelbaum and Sams 1987; Henderson 1990; Sluis 2002).

Planting of appropriate native species is known to accelerate succession in wetlands and enhance return to more natural conditions (Mitsch, Wu, Narin, Weithe, Wang, Deal, and Boucher, 1998). *Phalaris arundinacea* is affected by competition (Jones, Carlson, and Buxton 1988; Morrison and Molofsky 1998; Lindig-Cisneros and Zedler 2002; Maurer and Zedler 2002), especially competition for light (Jones and others 1988; Morrison and Molofsky 1998; Werner and Zedler 2002). After plot treatment, species arrays of either native woody plants or native herbaceous plants or seeds of native herbs were planted. Similar arrays of were planted directly into control plots.

For the native plant establishment tests, it was hypothesized that:

- Temporary reduction of *Phalaris arundinacea* monoculture cover and biomass by herbicide would facilitate the establishment of robust native plant species.

- Early-season burns would be ineffective for reducing *P. arundinacea* cover and biomass and would not facilitate the establishment of robust native plant species.
- Robust native plants, once established in *P. arundinacea* monocultures, would be able to compete with *P. arundinacea* and improve species richness.
- The relative height advantage of woody plants would make them effective competitors.

Hemiparasitic *Pedicularis lanceolata* as a Biological Control

This aspect of the project tested whether the native root hemiparasite *Pedicularis lanceolata* could use *P. arundinacea* as a host and create opportunities for other native plants to invade *P. arundinacea* monocultures. Hemiparasitic plants photosynthesize but draw nutrients from their hosts. The structure of an ecological community can be changed by attack on a dominant plant species by a non-specific hemiparasite (Vallauri, Aronson, and Barbero, 2002) or root antagonist (Ettema and Wardle 2002).

Pedicularis lanceolata is a wide-ranging root hemiparasite native to eastern North America. It is known to use diverse hosts in varying wetland habitats, primarily fens (Piehl 1965, Voss 1996). *Pedicularis lanceolata* is rare in the southeast despite having a large geographic range (Radford, Ahles, and Bell 1968). This rarity, despite a large range, implies that it is neither an aggressive weed nor agricultural pest. Innocuous habits are necessary for any biological control applied to a crop species. The hypotheses associated with this approach were that:

- *Pedicularis lanceolata* would be able to parasitize *Phalaris arundinacea.*
- Parasitism by *P. lanceolata* would reduce *P. arundinacea* biomass.
- The effect of *P. lanceolata* on *P. arundinacea* would facilitate growth of native plant species by creating an invasion window [plant establishment opportunity] by removal of a botanical barrier, as desribed by Johnstone (1986).

CHAPTER 2

MATERIALS AND METHODS

Three approaches were used to assess conditions in the Quarry Bog project area relative to *Phalaris arundinacea* habitat and species richness: The soil condition approach provides local background for general habitat requirements of *P. arundinacea*. The native plant establishment approach is limited to areas of established *P. arundinacea* monoculture and tests methods to establish other plant species there. The biological control approach tests the native root hemiparasite *Pedicularis lanceolata* on *P. arundinacea*.

Soil Conditions and *Phalaris arundinacea*

Soil conditions were surveyed along transects chosen to include areas of general species richness and native species of interest: 1) Little bluestem grass (*Schizachyrium scoparium*) on transect 3, generally the NW area of species richness. 2) Sphagnum moss (*Sphagnum* species), most common in the areas of species richness near transect 2, cranberry (*Vaccinium macrocarpon*) transplants (a local community project) have survived only in such *Sphagnum* cover. 3) White spiraea (*Spiraea alba*), generally at transition zones between species richness and *Phalaris arundinacea* predominance. 4) Woolgrass (*Scirpus cyperinus*), similarly a transition zone species, particularly near the channel through transects 1, 2, and 3 (Figure 1). Three transects crossing a ditch were established and surveyed for plant cover and species richness in 2001. A fourth transect, crossing what appears to be an abandoned roadbed and with a smaller ditch to the north, was established and surveyed similarly in 2002 (Figure 1).

Key:

Transects:

Ditch channels:

Raised drive (acts as dam):

Earthen dam:

Log & earth dam:

Probable abandoned bed of Virgil Crestinger Rd extension:

Arrows show drainage.

Piezometers represented by black diamonds: ◆

Plot # 30: ⊗ Other plots are N to NW of this diagram, beyond Locust Knob Branch (Appendix A).

Ovals represent areas *P. arundinacea* is sparse; it grows thickly elsewhere, including the ditches.

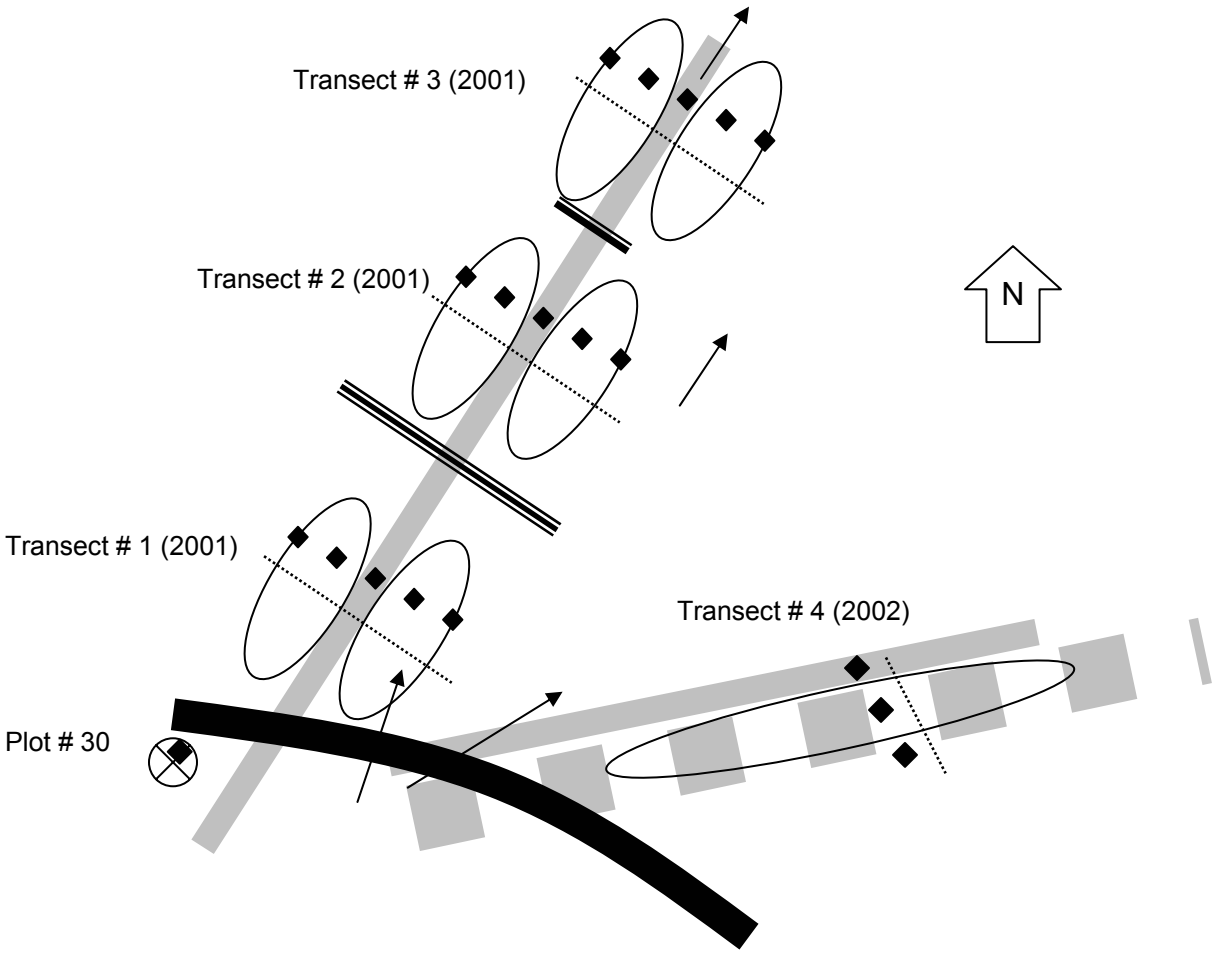

Figure 1. Schematic of transects to examine the relationship between soil characteristics and *P. arundinacea* abundance.

Not to scale. Dates are year of transect establishment.

Sampling points on each transect were 2 m apart. *Phalaris arundinacea* cover in a 1 m diameter ring centered on each point was estimated and classified into one of five categories: (0%), (> 0% to ~ 25%), (~ 50%), (~ 75% to < 100%), or (100%). Soil at each sampling point was tested for various properties: water content by dry weight, nitrogen (N, detected as nitrate, NO_3^-), phosphorus (P), pH, organic matter by dry weight, texture, and structure.

One sampling point of each transect was placed in areas with *Phalaris arundinacea* monoculture at the center of a ditch, with the rest of the transect crossing areas of little or no *P. arundinacea* growth until the line reached areas outside the ditch where *P. arundinacea* dominated again (Figure 1). On all transects, limits of *P. arundinacea* presence and predominance were marked to monitor shifts of its extent. Water table depth was monitored by piezometers installed parallel to each transect.

Piezometers

Each transect had one piezometer near each end and another at the middle; the three transects crossing the main ditch also had a piezometer on each slope (Figure 1). The piezometers were made of 4 cm diameter slotted PVC pipe and installed to a depth of approximately 60 cm (ACE 1993). They were installed in locations parallel to each vegetation sampling transect so that a piezometer was located in each area of *Phalaris arundinacea* predominance and each area of its absence. Coarse sand was used to backfill the hole to above the top of the slotted section, then the rest of the hole was sealed with bentonite clay. Readings of water depth were taken at least once a month; with efforts to sample extreme conditions of both drought and flooding.

Assessment of Plant Cover

Cover of the herbaceous layer was assessed in two ways. The limits of *Phalaris arundinacea* extent and the limits of its areas of predominance were marked with flags

at the time of establishment of each transect. The extent and predominance of *P. arundinacea* was inspected again at the time of final sampling in 2002. The intention was to record local *P. arundinacea* cover shifts during the experimental period.

Quantitative cover sampling was done before soil sample collection in the summer of 2002. Species within ½ m radius of each transect point were counted from above, identified at least to genus, and their cover estimated. The species richness recorded is a minimum because many immature plants of *Soildago*, *Carex* and *Rubus* were not identified to the species level because they lacked reproductive structures. The size of the sampling areas (1 m in diameter) also limited accuracy in estimating species richness. Voucher specimens were collected for selected monocot species and are deposited in the John C. Warden Herbarium at the Department of Biological Sciences, East Tennessee State University (see Appendix B: species lists for the Orchard Bog wetland project).

Soil Sampling

Soil samples were collected in the summer of 2002, using a soil corer[3], inner diameter = 10.5 cm, inner length = 15 cm. This tool has a removable piston for taking and ejecting uniformly sized sections of soil and forcing those sections out of the mechanism. As the piston caused noticeable compaction of some soil samples, two soil samples were removed from beside each sampling point. One sample from each point, collected using the piston, was used for textural and chemical analysis. The other sample was taken without the piston installed, for determination of structure, shallow profile, water content, water potential, and bulk density. Phosphorus (P) and nitrogen (N) levels were tested because those are the usual limiting nutrients in wetlands (Mitsch & Gosselink 1993; Tallowin and Smith 2001; Amon and others 2002; Drexler and Bedford 2002). For the chemical and textural methods, a vertical section through the

upper 10 cm of each sample's top layer of mineral soil was broken up and mixed by passing it through a 2 mm screen. Roots and particles too large to pass the screen were discarded. Samples were spread on plastic and air-dried for a week. Samples taken from the area of the planted plots received the same treatment, as did a single sample from the crest of a clay earthen dam, taken for purposes of comparison but not associated with a piezometer.

Water Content. A vertical section of each core was taken, weighed moist, dried at 105˚C to remove water, and weighed again (Blake and Hartage 1986). The difference in mass was ascribed to lost water content, which was divided by the dry mass of the section and converted to a percent of dry mass.

Nitrogen. N was detected in the form of nitrate (NO_3^-), following Bundy and Meisinger (1994). Approximately 10g of soil from each sample was weighed, the mass recorded, and the sample placed in a 250mL (or larger) flask. A 2M potassium chloride (KCl) solution was made by dissolving 745g KCl in 5L deionized H_2O; 100mL of the solution were added to each sample. The flasks were then shaken vigorously and shaken steadily for one hour. Fluid from the samples was centrifuged. Whatman # 42 filter paper and a suction apparatus constructed from a filter funnel, collection flask, and vacuum source was used to filter the supernatant. The first part of the supernatant was discarded, then the remainder was tested using parts from the Hach[4] cube test kit for low range saltwater NO_3^- testing: the low range NO_3^- test cube calibrated for salt water use, NO_3^- low range powder pillows, and NO_3^- reagent powder pillow. The saltwater kit was necessary because the freshwater kit would not tolerate the concentration of chlorine (Cl) involved with the KCl extraction process.

[3] Par Aide Products Co., Lino Lakes MN USA.
[4] Hach Co., Loveland CO USA.

Phosphorus. Kuo (1996) provided the method for extracting available phosphorus (P). A 0.01M calcium chloride (CaCl) clarifying reagent was made by adding 3.675 g of $CaCl•2H_2O$ to 2.5 L H_2O. Approximately 5 g of soil from each sample was put into flasks, and 50 mL of the reagent was added to each. The flasks were then plugged, shaken vigorously, and shaken steadily for one hour. Fluid from the samples was centrifuged. The Hach test used for this nutrient (Orthophosphate 0-50 mg/L test kit) used a blank of the sample solution for standardization, so filtering of the samples was not necessary.

pH. Hydrogen ion activity was measured using the pH method from Peech (1965). 20 g of soil from each sample was combined with 20 mL of deionized water, agitated at least once each 5 min. for ½ hr., and then allowed to sit for an hour, when the reading was taken from the soil-water interface.

Organic Matter. The proportion of soil organic matter was determined using hydrogen peroxide (H_2O_2) decomposition (Robinson 1927; Gee and Bauder 1986), a method that gives results suitable for purposes of comparison (Broadbent 1965).

Approximately one gram of soil from each sample was weighed and the mass recorded. Each soil sample was placed in a beaker[5].

Equal parts deionized water and 30% H_2O_2 were combined to make a 15% H_2O_2 solution, and 20 mL of that solution was added to each beaker. A steam bath apparatus was prepared by packing the bottom of a large, deep, glass container with small glass

[5] Acidic results from the pH test indicated that the samples were unlikely to be high in calcium carbonate, and the first beakers used were 250 mL in case the samples contained manganese dioxide or chromium sesquioxide, both of which decompose H_2O_2. Robinson's (1927) method is vulnerable to all three contaminants; Gee and Bauder (1986) recommend precautions against excessive foaming. After the first run of samples proved well-behaved, successively smaller beakers used in the later runs allowed more samples to be processed simultaneously.

vials, then filling the container and vials with deionized water to the top of the vials. The beakers containing the prepared samples were placed atop of the layer of vials. The main container with all its contents was covered with aluminum foil, placed on a heater in a fume hood, and gradually brought to boiling temperature, where bubbles of steam appeared under the vials. Water was replaced when necessary. When the sample preparations stopped bubbling, more of the 15% H_2O_2 solution was added to ensure the reaction was complete. When bubbling and color change ended, the decomposition solution was let evaporate to the sample surfaces. Then the processed samples were removed from the heat.

During the heat treatment, discs of Whatman # 42 ashless filter paper were individually weighed, formed into cones, and placed into funnels made from aluminum foil, set in the mouths of vials and flasks. The cooled samples were washed from their beakers into the funnels, filtered, and rinsed with deionized water. The paper and washed soil were allowed to air dry, then weighed again. Original mass of the paper filter was subtracted from the total to get the mass of the treated soil sample, and the treated mass was subtracted from the mass of the original sample to determine the amount of organic matter oxidized. The organic matter mass was divided by the original mass of the sample to obtain percentage of organic matter by weight.

Texture. Soil texture was analyzed using a simplified hydrometer procedure combining the methods of Day (1965) and Gee and Bauder (1979, 1986). The hydrometer procedure was chosen because Bouyoucos (1962) indicates that hydrometer analysis of a soil's mineral portion does not need preparation to eliminate organic matter from the sample, evidently on the assumption that the average density of saturated organic matter is close enough to the density of water to be within the procedure's margin of error. Some gross organic matter removal was necessary, however. As surface organic layers were often *Phalaris arundinacea* debris, root, and

rhizome mass, this layer was removed before analysis of texture for a more accurate estimate of soil conditions at the time of the grass' establishment.

A portion of at least 20 g was weighed out from each soil sample and oven-dried at 105˚C. The samples were then weighed and put into flasks of at least 600 mL volume. A particle dispersal solution of 50 g/L sodium hexametaphosphate was prepared by mixing 250 g of sodium hexametaphosphate [$(NaP0_3)_6$] with water until the solution volume reached 5 L and all the solute dissolved. Then 100 mL of the hexametaphosphate solution were added to each flask, the flask was shaken by hand to wet its contents, 250 mL of deionized water were added, and the flask was shaken again. The flasks were securely plugged, put on a mechanical shaker and shaken vigorously overnight.

The dispersal solution was standardized using the "highlight method" (Day 1965). In a 1 L graduated cylinder deionized water was added to 100 mL of the dispersal solution until the volume reached 1 L. A standard ASTM # 152H hydrometer, with Bouyoucos scale in g/L, was gently lowered into the standard and its reading taken. Agitated and dispersed soil samples were washed into 1 L graduated cylinders and deionized water was used to standardize the volume of each to 1 L. The cylinders were then firmly capped with a palm and mixed by inverting repeatedly for one minute. Exactly 90 minutes after mixing stopped for each individual sample, a reading was taken using the hydrometer. Exactly 24 hours after mixing stopped for each individual sample, another reading was taken. Both readings were combined with the original dry sample mass and standard reading to find the clay fraction of the sample, in accord with the corrected averaging equation best explained by Gee and Bauder (1979):

$$\% \text{ clay} = \frac{100}{2} \times \frac{(\text{24 hr. reading} - \text{standard}) + (0.867(\text{90 min. reading} - \text{standard}))}{\text{original dry weight}}$$

After hydrometer readings finished, sand fractions for the samples were found by washing each sample through a 270-mesh (53 micron) sieve (Gee and Bauder 1986). The final few rinses were made with deionized water. The sand remaining in the sieve from each sample was then washed from the sieve into beakers, the water drained off, and the sand allowed to dry. Foil weighing pans were individually weighed, the sand transferred to them, dried at 105˚C, and weighed again. The difference between the empty pans and pans with oven-dried sand was the mass of the sand. The sand mass was divided by the original dry mass of each sample to obtain a percentage.

Silt fraction was calculated by subtracting the organic fraction, clay fraction, and sand fraction from 100%. The remainder was the silt fraction, by process of elimination.

Structure. As surface organic layers were often *Phalaris arundinacea* debris, root, and rhizome mass, with little or no mineral soil included, this layer was ignored for structural analysis to get a better estimate of soil structure at the time of the grass' establishment. Structure of the top 10 cm of mineral soil (beneath any predominantly organic layer) was examined by hand for particle aggregation and other types of loose structure, versus compact, consolidated lack of structure.

Outflow Water Characteristics. Water flowing out of the project area was tested in spring and fall of 2001 and 2002 using an Oakton Instruments pH Testr 2[6] and YSI model 85 handheld oxygen, conductivity, salinity and temperature system[7].

Reducing conditions. In early summer of 2002, when final soil sampling began, the steel transect sampling point flag wires and plot posts had been in place for months. The steel was pulled, inspected for rust, and replaced. Rust indicated oxidizing

[6] Part 35624-20, Oakton Instruments P.O. Box 5136, Vernon Hills, IL USA.
[7] YSI Inc., 1725 Brannum Lane, Yellow Springs OH USA.

conditions, bare metal reducing conditions in the range of iron's reduction potential (Qualls, Richardson, and Sherwood, 2001). The distance from the level where the steel met the soil surface to the transition between rust and bare steel showed the depth to iron-reducing conditions.

Water potential. Water potential at submerged sampling points was determined by measuring depth before sample extraction (Brady and Weil 2000). For exposed soil, the McInnes, Weaver, and Savage (1994) principle was used. The samples collected for physical analysis were immediately sealed in individual airtight bags and allowed to reach a uniform temperature in insulated containers. Then two 70 mm discs of Whatman # 42 ashless filter paper were inserted into each bag, and the samples were turned to rest on top of them. After at least a day, the clean piece of filter paper not in direct contact with the soil sample was weighed immediately upon opening of each bag.

Small ovenproof plastic bags were used as drying containers. Each weighed disc was dried overnight at 105˚C in an open bag, and then the bags were individually removed from the drying oven, closed, and immediately weighed with their contents. The paper was discarded and the bags weighed empty; the difference was the weight of the dried filter paper alone. The proportion of mass lost from the paper during drying was applied to the water potential chart in McInnes and others (1994).

Bulk density. The method chosen for determination of bulk density (Blake and Hartage 1986) requires a sample of known size to be extracted form the soil, dried, weighed, and its density calculated as mass/volume. As the collection apparatus took samples inconveniently large for drying, the vertical section of the cores used for water content determination was used instead of the whole core, the ratio of each section's moist weight to the weight of its parent core used to correct the figures after drying.

Statistical analysis

Statistical analysis used the program Minitab 13.1 (Minitab 2000). Ordinal logistic regression was used to analyze soil characteristics in relation to species richness and *Phalaris arundinacea* cover in the herbaceous layer of the associated sampling area. *Phalaris arundinacea* cover was categorized into five classes: (0%), (> 0% to ~ 25%), (~ 50%), (~ 75% to < 100%), or (100%). Nitrogen (N) data from nitrate (NO_3^-) was tested as a categorical variable because only 5 out of 46 samples had a NO_3^- level detectable by the assessment method used (John Kalbfleisch, ETSU, personal communication). A similar analysis compared soil properties with species richness, and a standard linear regression related *P. arundinacea* cover to species richness.

Water table data from piezometers was an exception to the sampling number and cover category rule. Piezometer location was in areas of either *Phalaris arundinacea* predominance or absence. The project installed 18 transect piezometers and readings were taken at least monthly for more than a year. No piezometers were installed in transition areas with intermediate cover values. For regression analysis of water table data, two categories of *P. arundinacea* cover were used: predominance or absence. Water table vs. *P. arundinacea* cover regression was binary and conducted separately from analysis of the other transect data. For the sake of consistency, water table values used for statistical analysis were limited to data collected after the establishment of transect 4. Because species richness was not recorded at piezometer locations, water table data could not be directly analyzed relative to species richness.

Native Plant Establishment in *Phalaris arundinacea*

In six areas of Orchard Bog where *Phalaris arundinacea* grew in dense monocultures, circular plots with a radius of three meters were established and treatments were randomly assigned to each plot (Appendix A). Plots that were not used as controls were treated with either spring burning or herbicide prior to planting the native species. Within the 12 plots given each treatment, equal numbers were then randomly planted with one of three arrays of native species: transplanted herbaceous species, transplanted woody and understory species, and seeds of herbaceous species (Table 1). Plots not receiving transplants were worked with a shovel to provide consistent plot conditions by imitating the soil disturbance caused by transplantation.

Table 1.
Experimental plan for native plant establishment in *P. arundinacea* monocultures.

Randomly selected plots of *Phalaris arundinacea* monoculture were treated with controlled burns, the glyphosate herbicide Rodeo, or left as controls. Three different arrays of native species were planted into each preparation, with controls left unplanted. Species characteristic of a woody wetland (swamp) and herbaceous wetland (marsh) were transplanted. Additionally, herbaceous species were planted as seed.

	P. arundinacea treatments		
Species array	Control	Burned	Herbicide
Woody plants	3	3	3
Herbaceous plants	3	3	3
Herbaceous seeds	3	3	3
Unplanted control	3	3	3
Total, each treatment:	12	12	12

All species planted were wetland species native to the Shady Valley area (Table 2). Woody plants are the predominant historical cover for the region (Barclay 1957) and tall herbs are a valid cover type for rich fens (Wheeler and Shaw 1991). These plants were propagated from individuals already growing in Shady Valley whenever possible.

Planting of the herbaceous array was accomplished in May 2001 at 8 plants/m^2 (224 plants/plot) in concentric circles of varying diameter, rings of the same species no more than 1 m apart. One more species of dicot was planted than monocot, but numbers of individual herb plants were equally divided between monocots and dicots. *Juncus effusus*, an upright and partially evergreen species, was planted first and used to guide planting of the dormant herb species in different rings.

Table 2.
Transplanted herbaceous species array (marsh vegetation)

Equal numbers of monocots and Dicots were planted into the plots designated for herbaceous transplants. All species used were native to the Orchard Bog project.

Latin name	Common name	Density/m^2	Source
Monocots			
Carex lurida	Shallow sedge	1	Orchard Bog area
Carex vulpinoidea	Fox sedge	1	Mail order[8]
Juncus effusus	Soft rush	1	Orchard Bog area
Scirpus cyperinus	Woolgrass, bulrush	1	Orchard Bog area
Dicots			
Asclepias incarnata	Swamp milkweed	1	Mail order[9]
Chelone glabra	White turtlehead	0.5	Sally Cove Creek, Unicoi County
Clematis virginiana	Virgin's bower clematis	1	Sally Cove Creek, Unicoi County
Eupatorium fistulosum	Joe-Pye weed	0.5	Orchard Bog area
Symphyotrichum puniceum	Swamp aster, Purple-stemmed aster	1	Sally Cove Creek, Unicoi County

[8] Southern Tier Consulting, 2701-A Route 305, P.O. Box 30, West Clarksville NY
[9] Pinelands Nursery Inc., 323 Island Road, Columbus, NJ

All seeds were purchased[10]. Species in the seed mixture were: swamp aster (*Symphyotrichum puniceum*), fox sedge (*Carex vulpinoidea*), wool grass (*Scirpus cyperinus*), swamp milkweed (*Asclepias incarnata*), shallow sedge (*Carex lurida*), and soft rush (*Juncus effusus*). Seed was mixed with damp vermiculite and hand spread onto the plots at a rate of 2.5 g seed/m^2. Then plots were lightly raked or vegetation swished back and forth to settle seeds onto the soil surface.

The woody species array was planted at a density of 3 plants/m^2 in each of the 9 woody species array plots, a total of 85 woody plants/plot (Table 3). Silky willow (*Salix sercia*) and common elder (*Sambucus canadensis*), were collected as unbranched basal (*S. sercia*) or root sprouts (*S. canadensis*) from shrubs top-killed by a controlled burn one year earlier. Both those shrub species were locally available and readily propagate asexually, a trait assumed to be a dual advantage for production of transplants and vegetative reproduction in monocultures of *Phalaris arundinacea*. Marsh fern (*Thelypteris palustris*) was purchased[11] to fill the role of an understory species and planted at a density of 1 plant/m^2, 28 /plot.

Table 3.
Plants for woody species array (swamp vegetation)

Two Dicot shrub species were planted into the plots designated for the woody species array. One fern species was planted to fill the role of an understory species. All species used were native to the Orchard Bog project.

Latin name	Common name	Density/m^2	Source
Salix sercia	Silky willow	2	Orchard Bog area
Sambucus canadensis	Elderberry	1	Orchard Bog area
Thelypteris palustris	Marsh fern	1	Mail order[11]

[10] Prairie Moon Nursery, Route 3, Box 1633, Winona, MN
[11] Southern Tier Consulting, 2701-A Route 305 P.O. Box 30 West Clarksville, NY

Salix sercia was transplanted at 2 /m^2 or 57 /plot; a total of 513 for all nine woody array plots. Shoots 50 to 100 cm long were cut in February 2001, before bud break. The severed ends of the shoots were dipped in the commercial fungicide and rooting hormone preparation Rootone and potted in three inches of a mix of milled peat and coarse sand, then the containers and cuttings were placed into large transparent plastic bags to prevent drying and set outdoors in a well-lit north-facing area protected from direct sunlight. The *S. sercia* cuttings tended not to maintain an adequate standard size (≥ 50 cm) while rooting so their planting was not accomplished until summer.

Plants of *Sambucus canadensis* 50 to 100 cm tall were dug from areas of the Orchard Bog wetland project before those areas were subjected to controlled burns in the spring of 2001. The plants were transplanted with roots and rhizomes attached. They made up the remaining 28 woody plants/plot; 252 total. Planting of this species was finished in mid-May; eight did not survive transplanting and were replaced in late May. The spring and early summer of 2001 were dry and woody species were hand watered to prevent further mortality until a wet period began in July.

Phalaris arundinacea Burn and Herbicide Treatments

Plots prepared with controlled burns were ignited in both late March and early April 2001. A second attempt was made because the earlier burns were incomplete. Though all plots were successfully ignited and burned in April, the second burn still did not achieve complete combustion of the litter layer because underlying litter was never entirely dry. A 1.5% solution of the glyphosate herbicide, Rodeo (a formula designed for aquatic habitats and known to be effective against *P. arundinacea* [Kilbride & Paveglio 1999]) with surfactant added (240 ml/15 L; a 0.8% solution) was sprayed on herbicide plots at a rate of 0.015 L/m^2 after *Phalaris arundinacea* growth reached approximately 25 cm in late April.

Data collection

Soil. In each of the six areas of plots with continuous *Phalaris arundinacea* monoculture, one soil sampling location was randomly chosen for assessment of soil conditions. The samples were collected and analyzed as already described in the soil section.

Piezometers. Shallow piezometers (~ 60 cm deep, as already described in the soil section) were installed in at least every other plot to monitor hydrology. Water levels in the piezometers were measured as described in the soil section and on the same days as when the transect piezometers were read. Plot piezometer readings were averaged for the date of collection.

Cover. Percent cover of *Phalaris arundinacea*, all other species, and exposed *P. arundinacea* litter were estimated in each plot in August of 2001 and 2002. Canopy species richness was recorded by counting the number of different species visible to a researcher standing at the center of each plot. The species richness recorded is a minimum; some plants of *Solidago, Carex* and *Rubus* were not identified to the species level because they lacked reproductive structures; plants invisible due to the *P. arundinacea* canopy were not included. Paine and Ribic (2002) used a simiar sampling procedure.

Biomass. Biomass collections were made in September following the cover estimates. Aerial[12] biomass samples were collected from three random subplots (½ m in diameter) in each plot, both years. The outermost plot area within ½ m of each plot's circumference was excluded from sampling to avoid edge effects. To select subplots

within the circular plots, a random value for area was generated and then converted to a diameter that could be measured from the central post. The resulting distance was combined with a randomly generated azimuth value. To avoid overlap of sampling areas with each other and the piezometers, extra sets of subplots were produced. Any set that had its subplots close enough together for the sampling areas to overlap was discarded. Subplot sets were checked at each plot before sample collection to ensure that their locations were not near either the piezometer or previously sampled areas.

All stems of *Phalaris arundinacea* that rose above the litter layer in the subplot were cut with hand clippers and stored out of direct sun in a plastic bag. After aerial biomass collection at each point, a 10.5 cm diameter core, 15 cm deep, was taken from the center of each cleared area with the previously described corer. Cores were sealed in a shaded plastic bag and then refrigerated on the day of collection. The cores were crushed and washed in buckets and basins and repeatedly filtered through pieces of standard fiberglass window screen to extract subterranean biomass[13].

Litter and biomass samples were taken to the John C. Warden Herbarium, East Tennessee State University, frozen on the day of collection for preservation and elimination of insect pests, then transferred to paper bags and dried at 40 - 45°C[14] for three to seven days. Dryness was confirmed when samples removed from the cabinets gained centigrams of mass on a balance when allowed to absorb atmospheric humidity.

Statistical analysis

All statistical analysis used the program Minitab 13 (Minitab 2000). Balanced three-way ANOVA was used to assess the interaction effects of year, *Phalaris*

[12] Because thick *P. arundinacea* root mats made the exact location of ground surfaces debatable, this paper uses the term “aerial” to refer to biomass collected from above the *P. arundinacea* litter layer and the term “subterranean” for biomass below the surface of the litter layer.
[13] The standard plastic y-type garden hose divider, with circular valves, is recommended for this purpose. These tools produce narrow, intense, and easily adjustable streams of pressurized water.
[14] A dial setting of 150 in the John C. Warden Herbarium’s convection drying cabinets.

arundinacea plot treatment, and planting array. Where raw data distributions were not suitable for ANOVA analysis, a second ANOVA after mathematical conversion of the data set was used to verify the initial ANOVA procedure (John Kalbfleisch, ETSU, personal communication). Comparison of means used the Bonferroni simultaneous comparisons procedure (S-PLUS 2000). The Kruskal-Wallis nonparametric procedure was used to analyze one data set that could not be transformed to fit the requirements of ANOVA.

Paired comparisons between 2001 and 2002 data were possible because the same plots were sampled each year. The paired t-test was used on normally distributed data sets. Transformation of data was not useful to obtain results significant at $p \leq 0.05$ with paired t-tests. The Wilcoxon rank sum test was used when one or both data sets in a pair were irreconcilably nonparametric (Minitab 2000).

Biomass. Balanced three-way ANOVA (using plots within treatments, within plot arrays, as the error term [48 df]) was used to assess the interaction effects of year, *Phalaris arundinacea* treatment, and planting array on *P. arundinacea* mass. Data were converted from g/(the original area of sampling) to g/m^2. The categories of aerial and subterranean biomass were analyzed separately and as a ratio of aerial biomass divided by subterranean biomass (shoot/root ratio). All data sets derived from plot mass collection did not produce a normally distributed set of residual values and so required a second ANOVA after square-root transformation to confirm the initial ANOVA procedure (John Kalbfleisch, ETSU, personal communication). Comparison of means within factor groups used the Bonferroni simultaneous comparisons procedure (S-PLUS 2000). Differences between years and within factor categories were detected with paired tests after averaging of the three sub-samples for each plot. Paired data sets that shared normal distributions were given paired t-tests, otherwise the nonparametric Wilcoxon rank sum test was used (Minitab 2000).

Species Richness and Cover. Species richness data was tested by balanced three-way ANOVA before and after conversion by log-10 transformation. Plant cover proportion data was tested similarly but converted using arc-sine-square-root transformation. Comparison analyses within factor groups were done using the Bonferroni simultaneous comparisons procedure (S-PLUS 2000). Litter cover data could not be analyzed between *Phalaris arundinacea* treatments because exposed litter values were predominantly zero. Changes between years were detected with paired tests. Paired data sets that shared normal distributions were given paired t-tests, otherwise the Wilcoxon rank sum test was used (Minitab 2000).

Data for analysis of differences between survival of planted monocot and dicot species were extracted from cover records and visible species richness data from the plots planted with herbs. Cover data were analyzed by balanced ANOVA, and verified with a second balanced ANOVA after arc-sine-square-root transformation (John Kalbfleisch, ETSU, personal communication). Planted species richness data did not require transformation to fit the requirements of ANOVA. The recorded number of visible blooming or fertile stalks of Joe-Pye weed (*Eupatorium fistulosum*) was analyzed by the Kruskal-Wallis test. Odland (2002) similarly used fertile shoot number to assess vigor for a perennial *Phalaris arundinacea* competitor. Because of a predominance of zero values, this *E. fistulosum* data could not be transformed to qualify for testing by ANOVA. Annual differences within factor categories for monocot and dicot data were checked using both the paired t-test and Wilcoxon signed rank test because the low sample count (3) within sample types reduced the distinction between normal and nonparametric distributions.

Hemiparasitic *Pedicularis lanceolata* as a Biological Control

Experimental Design

A container experiment was conducted on the grounds of the Powell Observatory at East Tennessee State University. Containers were five-gallon buckets with two 2/3 cm (= ¼ inch) drainage holes drilled on opposite sides, 10 cm from the bottom. This hole location was intended to prevent complete drainage and imitate the high water table of wetlands. Watering was from the top, with a hose, a pistol-type spray attachment, and municipal water, as often as necessary to keep the soil surface moist. The containers were filled to 10 cm from the top with subsoil collected in Johnson City, which is near Shady Valley and has the same basic bedrock type as that valley's floor (Tennessee, 1966). The remaining top 10 cm of the containers were filled with bottomland Shady Valley topsoil. Containers were chosen for ease of maintenance and monitoring and to avoid premature introduction of *Pedicularis lanceolata* to the Shady Valley wetland project.

Host plants (*Phalaris arundinacea*, *Juncus effusus, Clematis virginiana*, and *Scirpus cyperinus*) were grown in flats, transplanted to the containers, and allowed six weeks to establish. The containers were divided equally between two different host systems. One host system had only 3 plants of *P. arundinacea* in each container. The other system added 1 plant from each of 3 native host species (*J. effusus, C. virginiana*, and *S. cyperinus*) to the 3 plants of *P. arundinacea* in each container (Table 4). *Pedicularis lanceolata* seeds were purchased and sown after at least 30 days of stratification [cold storage with slightly moist sand], they were inserted into soil at the base of host plants and covered with a thin layer of Shady Valley topsoil. Soil deposition is consistent with *P. arundinacea* habitat (Klopatek 1978; Odland 2002; Werner and Zedler 2002). Controls of each host system omitted *P. lanceolata*. Half of the controls were planted with seeds of *Chelone glabra* (white turtlehead) as an additional non-parasitic control (Table 4). Both *P. lanceolata* and *C. glabra* are native

wetland perennials. They are considered closely related and are traditionally placed in the family Scrophulariaceae (Radford and others 1968)[15].

Each combination was replicated six times in a randomized block design, each block consisting of a set of one of each of the host and treatment combinations. The containers were spaced far enough to walk between, and weeded of unintended species so *Pedicularis lanceolata* had only the test species available as hosts.

Table 4.
Experimental plan testing *P. lanceolata* as a biological control of *P. arundinacea*

All containers had three plants of *Phalaris arundinacea*. Containers with mixed hosts also included one plant each of *Juncus effusus, Clematis virginiana*, and *Scirpus cyperinus*. *Chelone glabra* was used as an additional nonparasitic control for the hemiparasitic *Pedicularis lanceolata.*

	Treatment: species planted as seeds		
Host system	None: control	*C. glabra*: control	*P. lanceolata*
P. arundinacea only	6	6	6
Mixed hosts	6	6	6
Total, each seed sp.	12	12	12

The host plants of *Phalaris arundinacea* were collected in spring of 2001 as seedlings from the Orchard Bog wetland project area. *Juncus effusus* and *Scirpus cyperinus* seeds were collected earlier at the same general location, from seed heads that had retained their seeds after having fallen into standing water. *Clematis virginiana* and *Chelone glabra* seeds were collected from a riparian wetland bordering Sally Cove Creek (on the northwest side of Clarke Mt., TN, east of Unicoi, TN) in the same season. The seeds of *C. glabra* were refrigerated moist until the host plants were established.

[15] Though the genus *Pedicularis* has recently been suggested as more appropriately classified in the

The host combinations grew outside during the summer of 2001 on the grounds of the Powell Observatory, East Tennessee State University. After *Phalaris arundinacea* foliage died back in fall, the containers were stored on site between leaf bales. The container tops were not covered. When growth resumed in spring of 2002 the containers were separated again, and stray leaves removed from the soil surface. There was no winter mortality among the host species.

Seeds of *Pedicularis lanceolata* and *Chelone glabra* were planted into their assigned containers in late July of 2001, again in the fall of 2001 before container storage, and again after removal from storage in spring of 2002. All containers were given identical reseeding treatments, whether or not plants of the desired species had already established. Seeds of *P. lanceolata* planted in fall of 2001 were not cold-stratified (prepared by moist refrigeration to imitate the passage of winter and trigger growth) but it was necessary for those planted in spring and summer. Because all other seeds were collected after natural exposure to the winter of 2000-2001, then planted immediately or refrigerated still moist, all of them were considered cold-stratified.

Data Collection

Biomass was collected in the fall of 2002 to assess the root hemiparasite's effect on *Phalaris arundinacea, Clematis virginiana, Juncus effusus,* and *Scirpus cyperinus*. For the host species, only aerial biomass was collected. Because several plants of *Pedicularis lanceolata* had entered dormancy after setting seed in the summer or early fall of 2002, major roots of both *P. lanceolata* and *Chelone glabra* were collected along with those species' aerial portions. All samples were frozen overnight to kill any insects, and then dried in the John C. Warden Herbarium's convection drying cabinets at 40 to 45 °C for three days and nights. Dryness was confirmed when the largest samples gained centigrams of mass on a balance when allowed to absorb atmospheric humidity.

Orobanchaceae, its relationship to the Scrophulariaceae is still considered close (Young 1999).

Statistical Analysis

Three-way balanced ANOVA, using blocks as the error term, was used to test differences in treatment categories and verify a lack of block effects. Linear regression was used to compare biomass of *Pedicularis lanceolata* with the biomass of its host species (Minitab 2000). *Chelone glabra* biomass was given similar analyses for purposes of comparison.

CHAPTER 3

RESULTS

Soil Conditions and *Phalaris arundinacea*

Phalaris arundinacea and Soil Properties: Regression Analysis

The only soil properties significantly correlated with *Phalaris arundinacea* cover were pH and soil structure (Table 5). The project area's consolidated subsoil tended to exclude *P. arundinacea*. Positive correlation of *P. arundinacea* cover with high pH proved a poor predictor (Figure 2). In this paper, the term "consolidated" for soil structure should not be assumed to include soil that is merely compacted. Subsoil used for preliminary assessment was so consolidated that samples from submerged areas needed repeated additions of water before they were soft enough to be molded for a manual texture estimation technique (Brady and Weil 2000).

Table 5.
Soil properties as predictors of *P. arundinacea* cover

Ordinal logistic regression. Nitrogen (from nitrate) and soil structure were tested as categorical variables.

Predictor	Coefficient of regression	SE Coef	Z	P
pH	-5.654	1.769	-3.20	0.001
Water	1.062	1.569	0.63	0.499
Clay	2.48	71.15	0.03	0.972
Sand	-16.49	70.80	-0.23	0.816
Silt	-35.76	70.98	-0.50	0.614
Organic	-34.42	72.06	-0.48	0.633
Phosphorus	-1.327	1.215	-1.09	0.275
Nitrate N	-1.751	1.426	-1.23	0.220
Soil structure	-1.9151	0.7182	-2.67	0.008

It should be noted that the data set for pH contains a single outlier value (5.9) that evidently affected the regression for pH. The outlier was in an area of *Phalaris arundinacea* abundance and appears to have attracted the regression line (Figure 2).

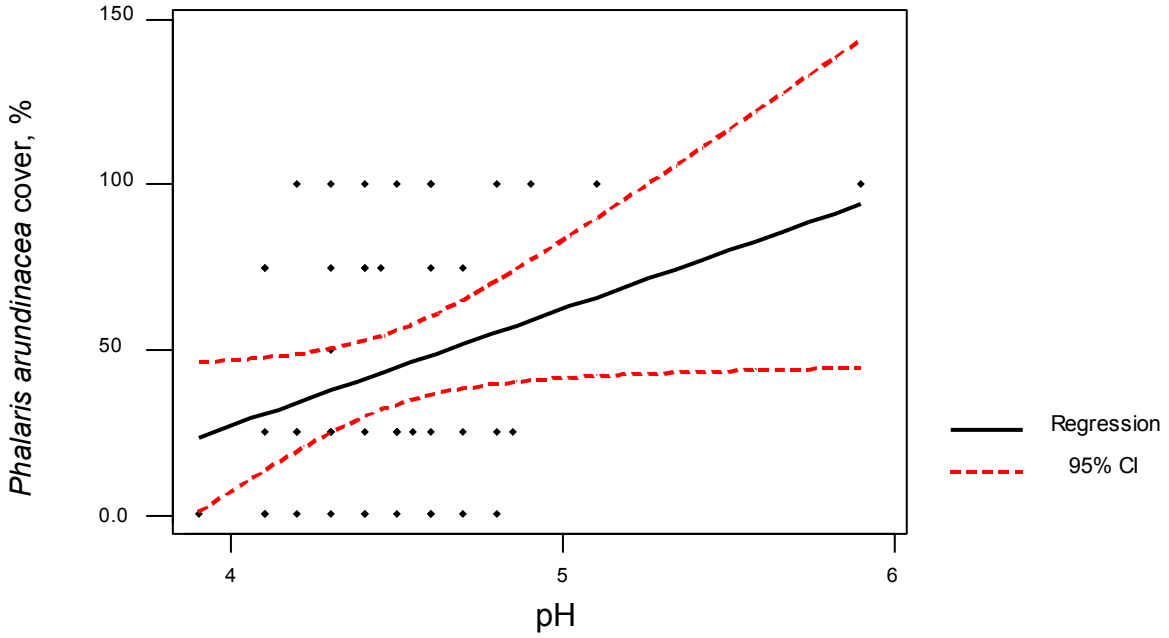

Figure 2.
P. arundinacea cover vs. pH, linear regression.

Standard linear regression analysis of pH as a predictor of *Phalaris arundinacea* cover appears attracted to an outlier value (pH 5.9). Dotted line is 95% confidence interval of the mean (CI).
Extension of the regression line to pH values of 6.5 or higher would increase the *P. arundinacea* cover proportion above 100%, a logical impossibility.
R = 0.3, adjusted r^2 = 0.07, p = 0.042, for this standard linear regression (Table 20, Appendix C).

The apparent attraction effect of that outlier value displayed in Figure 2 raises doubt about the significance of pH as a predictor. The regression line becomes logically impossible near pH 6, and the confidence interval diverges from the regression line at a relatively wide angle (compare to CI of Figure 3). While Figure 2's pH regression

probability (p) value is significant at < 0.05, the correlation coefficient (r) and adjusted r^2 values (0.3 and 0.07, respectively) are not significant (< 0.5 and < 0.25, respectively).

Table 6 shows data distributions for the soil properties tested. In contrast to pH, the single outlier value within soil structure data ran counter to the statistical trend instead of enhancing it. All 12 of the areas without *Phalaris arundinacea* cover had consolidated soil. Only one area (out of 19) with >~ 50% *P. arundinacea* cover was on consolidated soil at the time of sampling.

Table 6.
Distribution of soil properties tested by logistic regression

Note: Nitrogen levels are shown in their quantitative form.

Continuous data

Predictor	Mean	Median	Maximum	Minimum	SEM
pH	4.5	4.43	5.9	3.9	0.0486
Water (% dry mass)	0.76	0.68	2.10	0.44	0.0457
Clay (% dry mass)	0.23	0.23	0.42	0.11	0.0102
Sand (% dry mass)	0.37	0.39	0.59	0.02	0.0235
Silt (% dry mass)	0.26	0.25	0.53	0.15	0.0122
Organic (% dry mass)	0.15	0.12	0.37	0.04	0.0115
Phosphorus (ppm)	0.28	0.16	1.48	0.00	0.0483
Nitrate N (ppm)	5.63	0.00	110	0.00	3.21
Water table (cm)	-17.8	-15.5	59.0	-72.5	2.12

Categorical data (entries are numbers of observations within categories)

Predictor: soil structure	*Phalaris arundinacea* cover categories				
	0%	>0% to ~25%	~50%	~75% to <100%	100%
Loose	0	6	1	8	9
Consolidated	12	9	0	0	1

Classification of mineral particle texture varied from sandy loam through sandy clay loam, loam, clay loam, silty clay loam, and silty clay to clay, according to the mineral fraction textural analysis triangle in Gee and Bauder (1986). Most samples

showed substantial clay content and all had a wide range of particle sizes, meaning that they were poorly sorted.

Water table, measured by piezometers, could not be tested in the same regression as the soil characteristics because there were fewer piezometers than sampling points, and the piezometers were sampled more often. Therefore, the number of values from piezometer data did not correspond to the number of values for the other variables. The binary regression of piezometer data with soil structure was performed separately (Table 7).

Table 7.
Water table vs. *P. arundinacea* cover regression

Binary logistic regression analysis.

Predictor	Correlation coefficient (r)	Adjusted r^2	SE Coef	Z	P
Water table	-0.001945	0.007	0.001281	-1.51	0.131

Maximum and minimum water table values in Table 6 were both from areas of *Phalaris arundinacea* predominance, supporting the conclusion from the r and p values (Table 7) that water table height is not a primary determining factor for the species in the area sampled.

Species Richness and *Phalaris arundinacea* Cover

Regression analysis showed *Phalaris arundinacea* cover (as a proportion of the herbaceous layer) to be a predictor of plant species richness ($r = -0.883$, adjusted $r^2 = 0.78$, $p < 0.001$) (Figure 3).

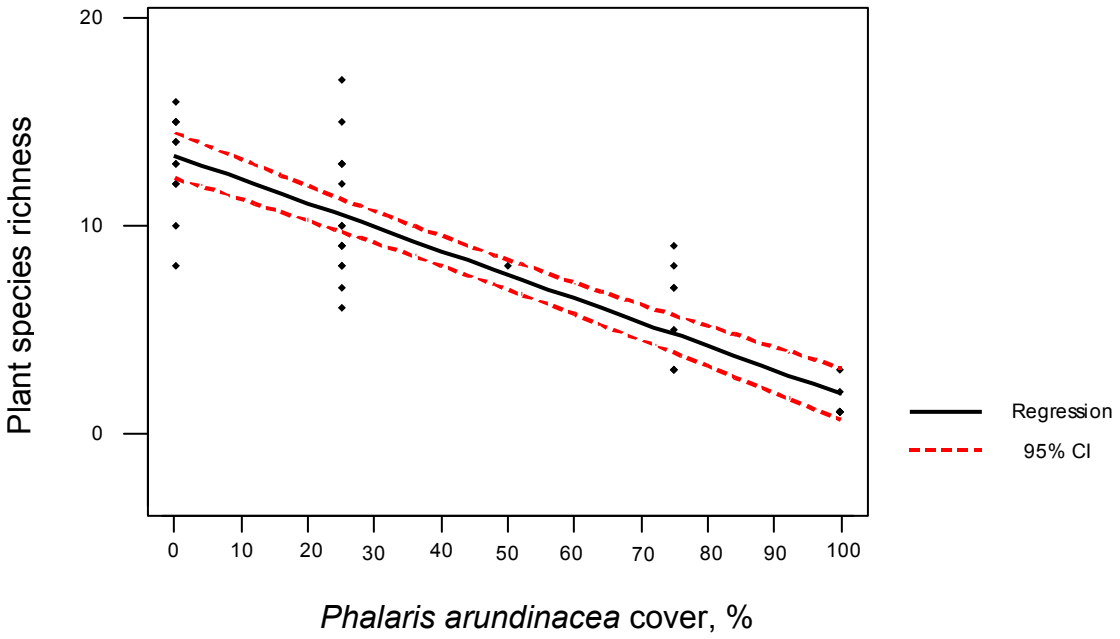

Figure 3.
P. arundinacea cover vs. plant species richness, linear regression.

Regression analysis of *Phalaris arundinacea* cover as a predictor of plant species richness in a 1m diameter circle, correlation coefficient (r) = -0.88, adjusted **r^2 = 0.78**. Dotted line is 95% confidence interval of the mean (CI). Regression p < 0.001 (Table 19, Appendix C).

Species Richness and Soil Conditions: Regression Analysis

Correlations between soil properties vs. cover of *Phalaris arundinacea* and, in turn, *P. arundinacea* cover vs. plant species richness were both significant (Table 5 and Figure 3). With that relationship in mind, soil qualities were tested by ordinal logistic regression as predictors of species richness in the Orchard Bog area. The only soil quality revealed as a significant predictor of plant species richness was pH (Table 8). Water table could not be tested by regression with species richness because species richness was not sampled around the points of piezometer installation prior to

installation, and the disturbance of soil and cover caused by piezometer installation would have compromised subsequent species richness data.

Table 8.
Soil properties as predictors of species richness

Ordinal logistic regression.
Nitrogen from nitrate was tested as a categorical variable.

Predictor	Coefficient of regression	SE Coef	Z	P
pH	3.652	1.416	2.78	0.006
Water	-1.411	1.345	-1.05	0.294
Clay	-123.81	68.42	-1.81	0.070
Sand	-112.66	67.38	-1.67	0.095
Silt	-97.11	66.86	-1.45	0.146
Organic	-95.84	67.72	-1.42	0.157
Phosphorus	0.238	1.085	0.22	0.826
Nitrate N	0.629	1.222	0.51	0.607
Soil structure	0.4805	0.5633	0.85	0.394

Soil structure was a poor predictor of species richness. The relationship between pH and plant species richness was weaker than between pH and *Phalaris arundinacea* cover, and the regression line of pH with species richness is dominated by an outlier value (Figure 4). The individual pH vs. species richness regression's p value, correlation coefficient (r) and adjusted r^2 values ($p = 0.07$, 0.27 and 0.052, respectively) are not significant (> 0.05, < 0.5 and < 0.25, respectively). The regression line becomes impossible above pH 6, where it predicts negative species richness, and its confidence interval again diverges at a wide angle (compare CI of Figure 4 to Figure 3's CI).

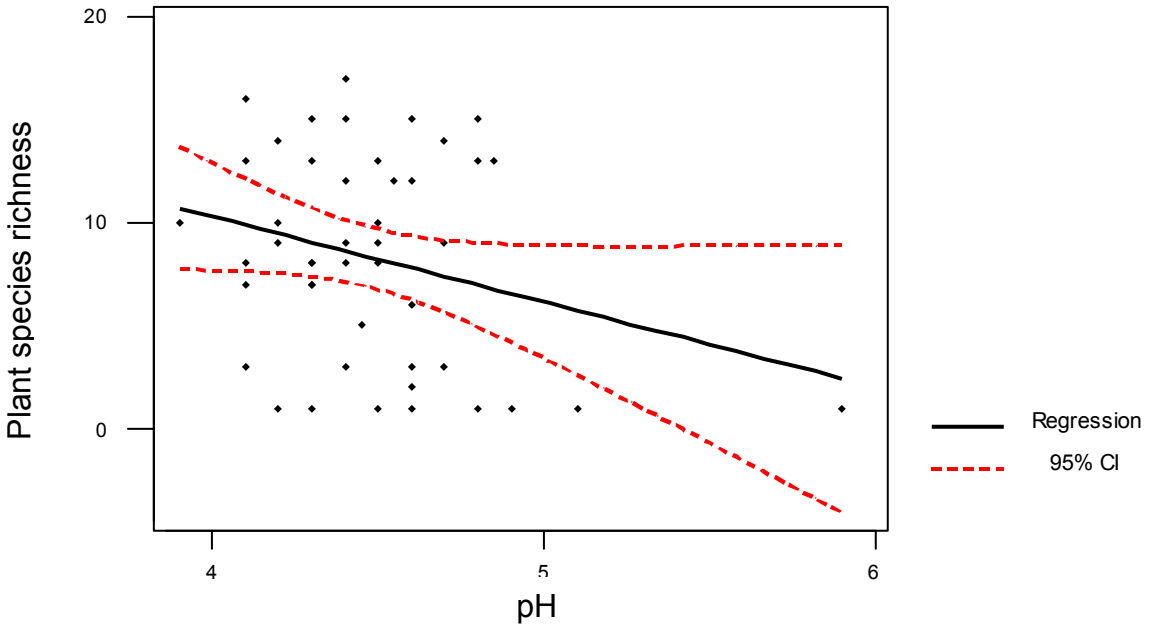

Figure 4.
Species richness vs. pH, linear regression.

Standard linear regression analysis of pH as a predictor of plant species richness appears attracted to an outlier value (pH 5.9). Dotted line is 95% confidence interval of the mean (CI). Species richness is a minimum due to sampling limitations.
Note that the regression line approaches 0 near the outlier value. Extension of the regression line to pH values above 6.5 would decrease the predicted species richness below 0, a logical impossibility.
R = 0.27, adjusted r^2 = 0.052, p = 0.069 (Table 20, Appendix C).

Shifts of *Phalaris arundinacea* Cover

At transect establishment, transition zones of *Phalaris arundinacea* cover were marked at two borders; areas of predominance in the herbaceous layer [> 50% cover] and at the limit of its extent [presence in at least trace amounts]. At sample collection in 2002, the current areas of *P. arundinacea* predominance and maximum extent were compared with the marked borders. All the areas where *P. arundinacea* was predominant became smaller, by approximately 1 m near the relatively dry transect ends (including all of transect 4) and roughly ½ m near the main channel running

through transects 1 – 3. Species that increased in cover near water tended to be *Scirpus cyperinus* and *Juncus* sp., on dryer sites they were commonly *Rubus hispidus*, *Carex* sp., and other members of the Cyperaceae.

At 13 of the 14 cover transition zones marked, areas of *Phalaris arundinacea* presence (in at least trace amounts) expanded while areas of its predominance diminished. The greatest expansions of *P. arundinacea* presence were at least 2 m on the NW side of transect 2, effectively eliminating an area where it was absent in the spring of 2001. The sole exception to the expansion of *P. arundinacea* presence was an inconsistent retreat (~ ½ m) on the NW end of transect 3.

Qualitative results

Outflow Water Characteristics. Discharge from the Orchard Bog project area via Locust Knob Branch was continuous during the study period. Salinity and conductivity levels in discharge water were not detectable by the equipment used. The pH in discharge water tended to be lowest when runoff was greatest, but was always higher (> 5) than the average soil pH (4.5). Discharge pH rose (> 6) when flow was slow and may have exceeded neutral during the driest weather, when no readings were taken.

Reducing conditions. Where not flooded, moss layers and the root and rhizome mat layers of *Phalaris arundinacea* were generally oxidizing, though conditions became reducing at the mineral soil surface on consolidated subsoil. Two points had neither moss nor a *P. arundinacea* root mat nor reducing conditions: one was in plot # 30 with *P. arundinacea* predominating, the other was on top of the clay dam where there was no *P. arundinacea* (see Figure 1). *Phalaris arundinacea* monocultures grew in both a drained plot without reducing conditions (plot # 30) and in ditch channels where reducing conditions started above the mineral surface (in the submerged litter layer).

Results of reducing condition tests were not suitable for statistical analysis because: 1) The steel posts and flag wires were not originally placed with the Qualls and others (2001) test in mind and so they were not installed to standardized depths, and 2) those probes did not all show evidence of reducing conditions[16].

Water Potential. All soil samples were moist beyond the tolerances of the McInnes and others (1994) test. However, *Phalaris arundinacea* grew in monocultures at the only sample location that resulted in a water/paper weight ratio of less than one (0.943 for plot # 30), in addition to all the submerged sampling locations. Water potential could not be statistically analyzed using weight ratios alone because water potential at submerged sites was measured as depth below the water surface.

Bulk Density. The bulk density test revealed *Phalaris arundinacea* root mat development, to 10cm deep or thicker, but was not subject to quantitative analysis for three reasons: 1) Sediments from ditch channels compressed substantially during coring, preventing the collection of samples with a known original size. 2) Mats of *P. arundinacea* roots and rhizomes were tough, compressible, and often not sharply differentiated from the mineral soil surface. Such mats could be trimmed off, but their lower limits and amounts of compression throughout the core during collection were unknown, so the original bulk of mineral soil was not determined. 3) A gravel and stone layer close to the surface of transect 4 made collection of uniform samples impossible.

[16] Two adjacent plots (numbered 5 and 34 in Appendix A) showed a yellow deposit on their posts, below the transition zone from iron-oxidizing to iron-reducing conditions. This deposit was the color of hard-boiled egg yolk and was accompanied by a sharp odor. It was not analyzed but may have been a deposit of elemental sulfur. Other posts to the N and NW had a similar deposit at approximately the same depth but it was a dark, slightly metallic, yellowish to olive-green color with no noticeable odor beyond a metallic scent. It may have been a compound of iron and sulfur, possibly the insoluble ferrous sulfate described in a different context by Gambrell and Patrick (1978). If the deposits on those posts did in fact result from sulfur oxidation, then the iron reduction technique of Qualls and others (2001) is also useful for detection of sulfur by precipitation of that element. The possibility that metallic iron was converted to reduced form in the Orchard Bog area is supported by the erosion of a flag wire with no accompanying sign of rust; reduced iron in water soluble (Gambrell and Patrick 1978).

Native Plant Establishment in *Phalaris arundinacea*

Plot Conditions

The average water table level among the plots ranged from +8.2 cm (above the soil surface) to -58.4 cm (below the soil surface) (Figure 5). Efforts were made to record extreme events, but short duration combined with adverse conditions caused maximum high-water levels to be missed, while insufficient piezometer depth caused low water extremes to be underestimated. In general, the experimental period from the spring of 2001 to early fall of 2002 was dry.

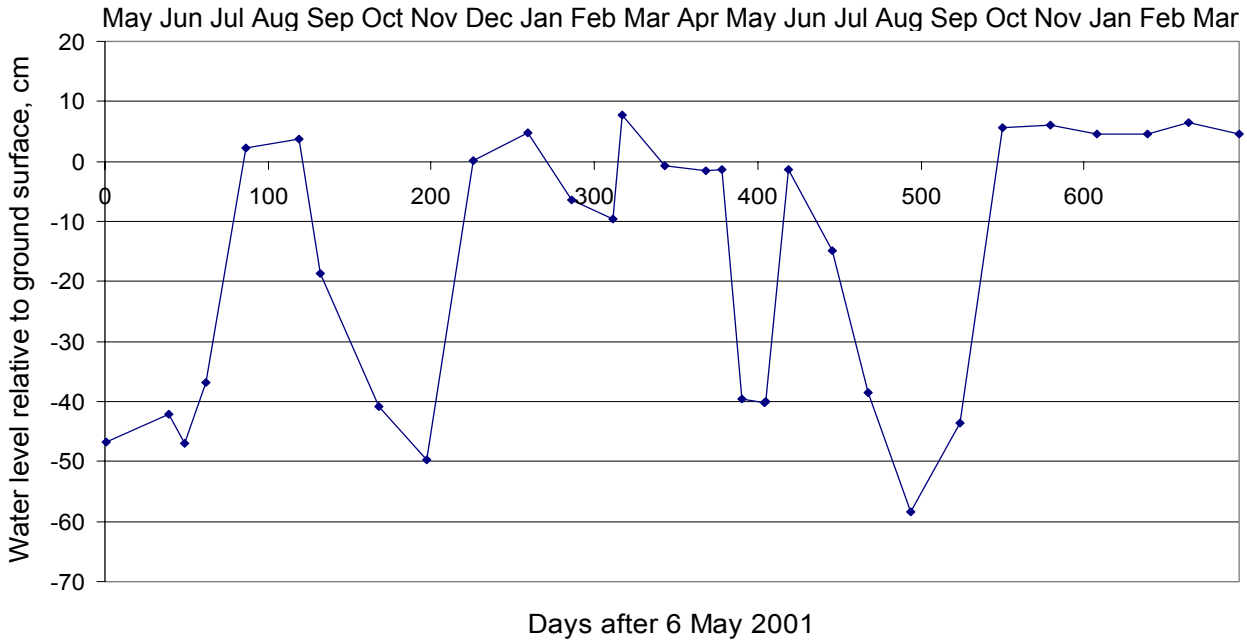

Figure 5. Average water table of planted plots

Water level extremes are conservative: High-water maximums were missed because they were brief and occurred during adverse field conditions. Low values could not be recorded when the water table dropped below the depth of the monitoring piezometers. At least one value in the calculation of all averages below -36 cm reflects maximum piezometer depth instead of actual water table depth.

Some plots tended to have a water table potential higher than any standing water present, other plots had a water table potential lower than standing water level. A few

plots never had any water at ground level or any sign (such as debris deposition) of flooding after storms. The presence of filamentous algae above the ground in some plots from the autumn of 2002 through March 2003 confirms a relatively constant water table for that period.

Plant Growth after Plot Treatments

Less than a month after controlled burns, *Phalaris arundinacea* seedlings were growing from many gaps in the litter layer of burned plots. Similarly, seedlings of *P. arundinacea* sprouted in masses from breaks in the layer of grass killed by herbicide, and there were clumps of surviving rhizomes. By late summer of 2001 only the plots treated with herbicide showed surviving *P. arundinacea* seedlings, and those seedlings accounted for most of the cover following herbicide treatment.

Rabbits browsed some plots severely in the year of planting, especially during dry periods and in plots treated with herbicide, where they seemed to prefer the middle of the plot. Deer browsed the taller dicots sporadically for the whole study period. By fall of 2002, most of the woody transplants that could be found had gnawing damage at their bases. Rodent tunnels were found in the *Phalaris arundinacea* root and rhizome mat of subterranean biomass samples.

Mortality among both herbaceous and woody dicot transplants was high in their first winter. Though scattered, surviving woody transplants tended to be tall enough to be found by the 2002 cover survey. Growing-season frosts on four different occasions (13 May 2001, 18 September 2001, 19 & 20 May 2002) damaged the dicot transplants, with *Eupatorium fistulosum*, *Clematis virginiana*, and *Chelone glabra* most severely affected. Many damaged individuals did not survive. Consequently, transplant mortality arising from either competition from *Phalaris arundinacea* or the suboptimal growing medium of an aerated root mat where *P. arundinacea* had been killed by herbicide was indistinguishable among the effects of frost and herbivory.

In 2001 the cover survey identified 11 annual species in various plots, mainly in plots subjected to herbicide. Annuals were also present in more than trace amounts in plot # 4, a relatively elevated burned plot located near an area of relative species richness (the partially-filled Locust Knob Branch ditch, Appendix A) representing a source of seeds. Plot #15, treated with herbicide and near the same seed source, had the maximum number of annual species, six. In 2002 the only annual species found during the cover survey was one *Polygonum*, though a second species of the same genus was discovered during biomass collection.

The only notable germinations from seed either involved species not planted, plots not seeded, or both in combination. The two perennial wetland dicots to increase their cover between 2001 and 2002 were volunteers following herbicide treatment, boneset (*Eupatorium perfoliatum*) in plot # 15 and ironweed (*Vernonia noveboracensis*) in plots # 6 & 32 (Appendix A). Both species bloomed in the fall of 2002, as did at least one *Solidago* species with the *E. perfoliatum* in plot # 15. That plot had the most volunteer seed activity; the plot maximum of six annual species was identified there in 2001. Numbers of other dicots decreased from 2001 to 2002. No mature *E. perfoliatum* was found outside of Plot # 15.

Phalaris arundinacea Mass Analysis

Three-way balanced ANOVA revealed significant differences in *Phalaris arundinacea* biomass, litter mass, and shoot/root ratio, mostly associated with different treatments (Table 9). A second analysis after square-root transformation of raw data values confirmed the ANOVA results from raw data and occasionally revealed an additional significant result (Table 9). Additional analysis of factors used interaction mean square values as error man square values to calculate F and p values of terms relative to the interactions. No additional statistical significance ($p > 0.05$) was found for any term using this process.

Table 9.
P. arundinacea sample mass and shoot/root ratio

Three-way balanced ANOVA. Abbreviations: Year = Yr, Plot treatment = Tre, Plant array = Ar.
Shoot/root ratios = (aerial biomass) / (subterranean biomass) from raw data, before averaging.
All data sets on this table were square-root transformed. All test error DF = 144.
See Appendix C, Tables 21 through 23, for a breakdown of significant factors.

		Aerial biomass				Subterranean biomass			
		Raw data		Transformed data		Raw data		Transformed data	
Source	DF	F	P	F	P	F	P	F	P
Yr	1	2.21	0.144	4.25	0.045	1.18	0.283	1.15	0.289
Tre	2	35.28	< 0.001	42.27	< 0.001	15.33	< 0.001	15.81	< 0.001
Ar	3	0.22	0.884	0.04	0.991	0.48	0.694	0.43	0.734
Yr*Tre	2	7.22	0.002	10.09	< 0.001	2.34	0.107	1.97	0.150
Yr*Ar	3	1.49	0.229	2.04	0.120	1.04	0.385	1.18	0.327
Tre*Ar	6	1.17	0.336	1.51	0.194	1.25	0.300	1.36	0.249
Yr*Tre*Ar	6	1.26	0.293	1.66	0.151	0.31	0.930	0.33	0.915
Plot error	48	2.55	< 0.001	2.69	< 0.001	1.65	0.013	1.64	0.013

		Shoot/root ratio				Litter mass			
		Raw data		Transformed data		Raw data		Transformed data	
Source	DF	F	P	F	P	F	P	F	P
Yr	1	0.54	0.465	1.34	0.254	0.03	0.861	0.74	0.395
Tre	2	6.28	0.004	8.63	0.001	31.35	< 0.001	38.13	< 0.001
Ar	3	0.04	0.990	0.05	0.985	0.07	0.973	0.16	0.922
Yr*Tre	2	6.05	0.005	8.6	0.001	1.84	0.170	3.61	0.035
Yr*Ar	3	0.04	0.990	0.20	0.897	0.40	0.756	0.44	0.725
Tre*Ar	6	1.15	0.351	1.33	0.261	0.97	0.459	1.04	0.413
Yr*Tre*Ar	6	0.49	0.811	0.68	0.666	0.73	0.630	0.80	0.574
Plot error	48	4.10	< 0.001	3.73	< 0.001	1.23	0.180	1.16	0.244

The plot error (difference between plots) in Table 9 was anticipated and in fact desired, as it shows that the experiment's effects were significant despite varied local conditions. The plant establishment experiment's random selection method was designed to take plot error into account and prevent it from interfering with the statistical analysis. Figure 6 illustrates the *Phalaris arundinacea* litter mass and aerial and subterranean biomass results for two years following plot treatment. Appendix C

displays Bonferroni comparisons (Tables 21 - 23) paired test analysis of changes (Table 24) and basic statistics (Table 25) used in the following analyses.

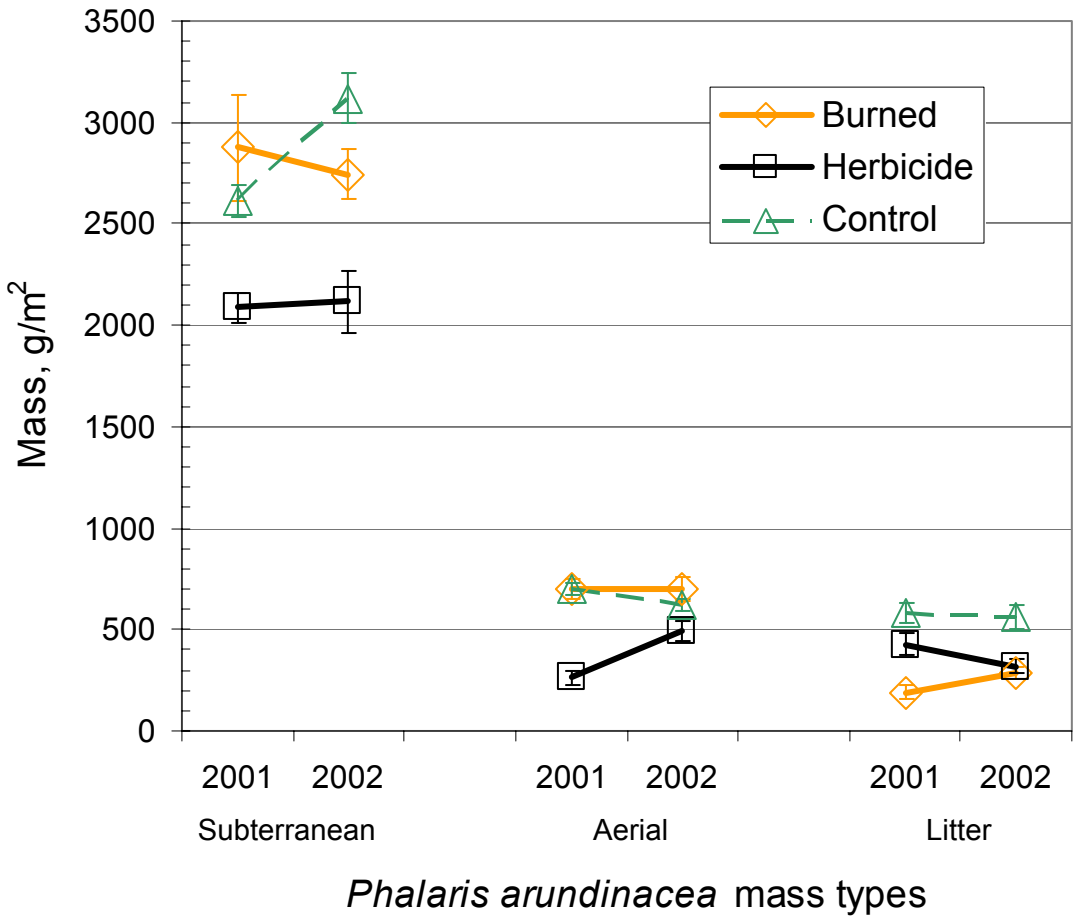

Figure 6.
Mass distribution of *P. arundinacea*, by treatment.

Plot preparations and planting were in the spring of 2001. Biomass was sampled in September.
Statistical significance comparisons are available in Appendix C, Tables 21 through 23.
Error bars are standard error of the mean.

Burned vs. Control Treatment: *P. arundinacea* Mass. There were no significant differences between control and burned treatment plots for *Phalaris arundinacea* biomass (Tables 21 - 23). *Phalaris arundinacea* litter mass was significantly less in the

burned plots, 33% and 51% of control plot values in 2001 and 2002, respectively (Tables 21 and 22).

Herbicide vs. Control Treatment: *P. arundinacea* Mass. Herbicide treatment significantly reduced *Phalaris arundinacea* 2001 aerial and subterranean biomass and litter mass to 37%, 80%, and 73% of control, respectively (Tables 21 and 25). In 2002 those respective values continued to be significantly different at 79%, 68%, and 57% of control (Tables 22 and 25). Shoot/root mass ratios following herbicide treatment were significantly less than control, 47% in 2001 (Tables 21 and 25) but not significantly different in 2002, at 116% of control (Tables 22 and 25). *Phalaris arundinacea* subterranean biomass was typically four times larger than aerial biomass, but months after herbicide exposure it was roughly eight times the aerial biomass (Table 25).

Herbicide vs. Burned Treatment: *P. arundinacea* Mass. Following herbicide, 2001 aerial and subterranean biomasses and litter mass were 37%, 73%, and 223% the values following fire, respectively, all 2001 values being statistically significant (Tables 21 and 25). By 2002 the respective biomass values were significantly 70% and 77% of control, but litter mass was not significantly different at 1.11% of control (Tables 22 and 25). Shoot/root ratios following herbicide were significantly reduced to 52% of the control value following fire in 2001, but there was no similarly significant difference in 2002 (Tables 21, 22, and 25).

Changes in Treatment Effect on *P. arundinacea* Mass, 2001 to 2002. *Phalaris arundinacea* treated with herbicide in 2001 significantly regained aerial biomass, recovered shoot/root ratio, and lost litter mass (to 187%, 185%, and 75% the 2001 values, respectively) by 2002 (Tables 24 and 25). The increase in aerial biomass can be attributed to recovery from herbicide, the ratio change attributed to the increase in

aerial biomass only, and the litter loss attributed to decay combined with diminished replacement from a low amount of aerial biomass. The root mat did not recover its reestablish as a distinct layer in two growing seasons after herbicide; it included few or no rhizomes at the end of 2002.

In 2002, control plots significantly gained subterranean biomass and reduced their shoot/root ratio (to 119% and 74% of 2001 values, respectively, Tables 24 and 25). Burned plots replaced some litter mass by 2002 (to 149% the 2001 value, Tables 24 and 25). No other significant mass differences were found between years (Table 24).

Cover and Species Richness Analysis

Cover proportion differences for *Phalaris arundinacea* and other species were transient and primarily influenced by plot treatments. *Phalaris arundinacea* cover also showed a significant response to planting method, and cover values differed between years. Species richness showed significant effects from both preparation and planting for the first year after plot establishment; species richness results were confirmed by a second ANOVA following log-10 transformation of the data set (Table 10). Most of the original analysis for raw cover data was confirmed after a second balanced three-way ANOVA following arc-sin-square-root transformation, but an interaction between preparation and planting method for cover of non-*P. arundinacea* species was not supported following transformation (Table 10).

Table 10.
Cover of *P. arundinacea* and other species, and species richness

Three-way balanced ANOVA. Abbrev: Year = Yr, *P. arundinacea* treatment = Tre, Plant array = Ar.
Cover data was arc-sine-square-root transformed, species richness was log-10 transformed.
See Appendix C, Tables 20 through 22, for a break-down of the significant factors. Error DF = 48.

		Live *P. arundinacea* cover				Cover of other species			
		Raw data		Transformed data		Raw data		Transformed data	
Source	DF	F	P	F	P	F	P	F	P
Yr	1	17.23	< 0.001	23.79	< 0.001	11.03	0.002	13.03	0.001
Tre	2	16.17	< 0.001	20.98	< 0.001	9.97	< 0.001	10.88	< 0.001
Ar	3	2.02	0.123	5.00	0.004	5.26	0.003	8.50	< 0.001
Yr*Tre	2	10.09	< 0.001	9.83	< 0.001	4.40	0.018	3.19	0.050
Yr*Ar	3	0.32	0.813	0.27	0.849	1.59	0.204	1.27	0.294
Tre*Ar	6	1.26	0.292	1.41	0.230	2.69	0.025	1.69	0.144
Yr*Tre*Ar	6	0.45	0.843	0.82	0.562	0.43	0.856	0.14	0.990

		Species richness			
		Raw data		Transformed data	
Source	DF	F	P	F	P
Yr	1	1.19	0.282	0.77	0.386
Tre	2	23.57	< 0.001	19.10	< 0.001
Ar	3	8.90	< 0.001	9.68	< 0.001
Yr*Tre	2	1.31	0.280	0.86	0.428
Yr*Ar	3	2.24	0.096	0.93	0.435
Tre*Ar	6	0.88	0.519	0.95	0.469
Yr*Tre*Ar	6	0.60	0.730	0.38	0.889

Additional analysis of factors used interaction mean square values as error man square values to calculate F and p values of terms relative to the interactions. No additional statistical significance ($p > 0.05$) was found for any term using this process. Appendix C displays statistical details used in the following analyses (Tables 21 - 24, and 26).

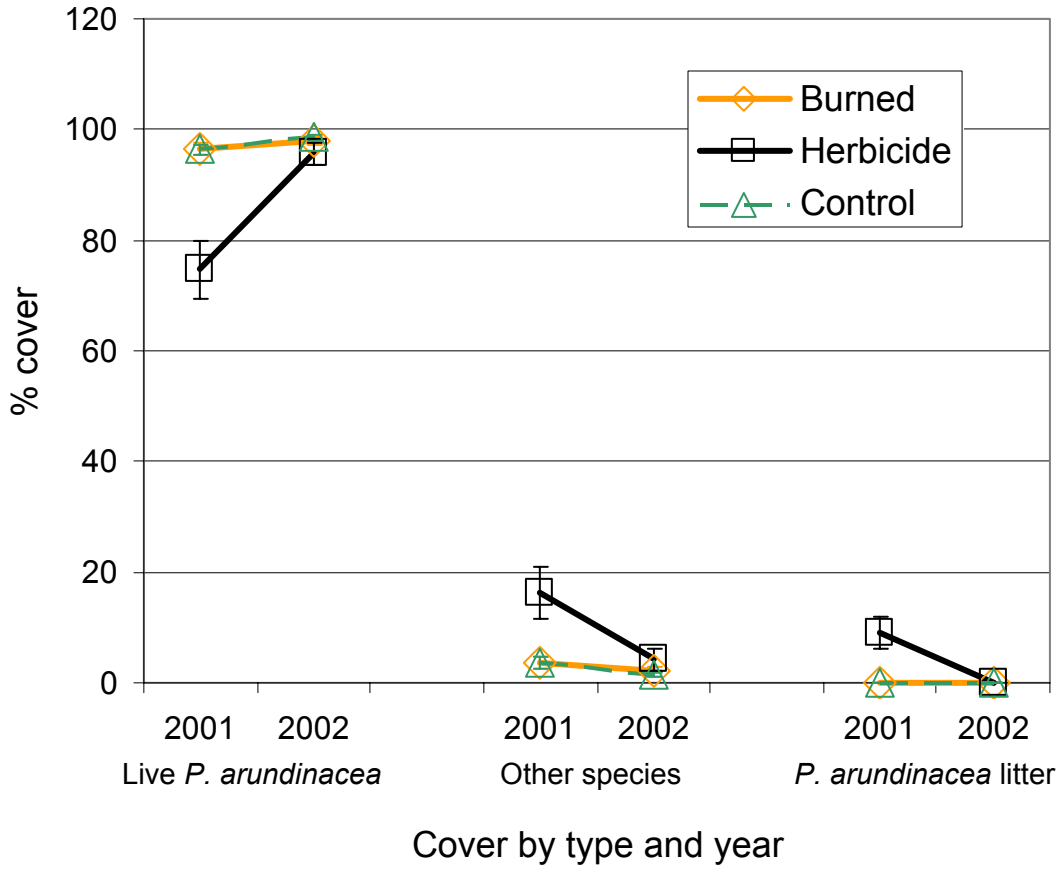

Figure 7.
Cover of *P. arundinacea* and other species, by treatment.

Plot preparations and planting were in the spring of 2001. Cover was recorded in August.
Error bars are standard error of the mean. Appendix C, Tables 21 through 23, shows significance levels.

Cover and *P. arundinacea* Treatment. Cover of *Phalaris arundinacea* was significantly reduced for the first growing season after herbicide treatment compared to the other plot treatments (burn and control; 78% for both, Tables 21 and 26), which did not differ significantly from each other (Figure 7, Table 21). Where *P. arundinacea* was treated with herbicide, cover of other species was significantly greater (443% more, Tables 21 and 26) than corresponding cover in both other plot types in 2001. None of

the cover differences after herbicide treatment on *Phalaris arundinacea* remained significant into the second year (Table 22).

Only plots treated with herbicide displayed exposed litter; 9.08% of their total cover. In 2001 a substantial proportion of litter cover was recorded in all but one of the plots given herbicide. By 2002 the only trace of exposed litter, in a single plot, was too small to quantify. The litter cover data contained too many zero values to analyze by ANOVA (Table 26).

Changes in Plot Treatment Effect on Cover, 2001 to 2002. The uniformity of cover among plots in 2002 is reflected in the significant gain of *Phalaris arundinacea* cover following herbicide (to 128% of 2001 value) and loss of cover for other species (to 26% of 2001 value, Tables 24 and 26). The disappearance of litter cover for the plots exposed to herbicide was significant (Tables 24 and 26).

There were significant changes for cover of *Phalaris arundinacea* and other species in the control plots, to 102% and 39% of 2001 values, respectively (Table 24 and 26). Evidently the difference for *P. arundinacea*, while slight, was relatively uniform across plots; paired tests are highly sensitive to uniform change. *Phalaris arundinacea* treatment produced no other cover differences between years (Table 24 displays all such significant differences).

Cover and Plant Array. Cover of the transplanted species was greatest in the year they were planted (Figure 8).

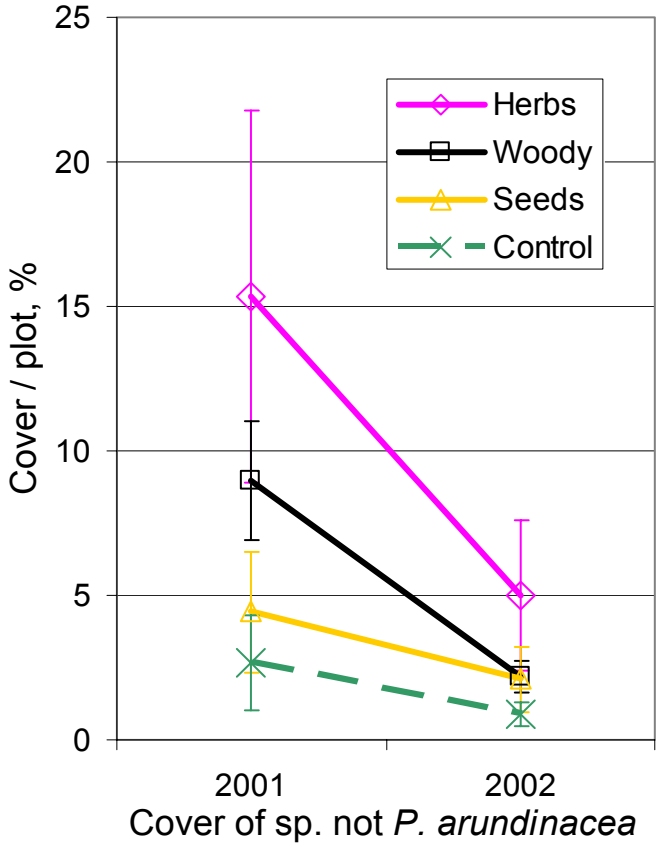

Figure 8.
Cover of species other than *P. arundinacea*, by planting array.

Planting was in May of 2001. Cover was recorded in September.
Error bars are standard error of the mean.

Planting Array Effect on Cover of Associated Species. Plots planted with herbs had a significantly greater amount of non-*Phalaris arundinacea* cover than either control or seeded plots in all pooled year (2001 + 2002) data (571% and 310%, respectively, Tables 23 and 26), and for transformed data of plots given herbaceous transplants vs. seeded and control plots in 2001 (345% and 574% more, respectively, Tables 23 and 26). The transformed 2001 data showed significantly more non-*P. arundinacea* cover in woody array plots than in control plots, (203% as much, Tables 21 and 26) but that was

the only significant difference associated with the woody array. Species cover was not significantly different between plots planted with seed and controls (Tables 21 - 23).

Planting Effect on *P. arundinacea* Cover. The differences in *P. arundinacea* cover proportion attributable to planting array are not illustrated, but are recorded in Tables 21 - 23 and 26. Those differences were logical counterpoints to the differences in cover proportion of other species; where the proportion of other species' cover differed, the cover of *P. arundinacea* differed accordingly and oppositely but with similar levels of significance.

Changes in Planting Effect on Cover. The significant drop in cover for plots given woody and herbaceous transplants (to 25% and 33% of 2001 values, respectively, Tables 24 and 26) reflects cumulative transplant failure, which was particularly severe among dicots. It was accompanied by similar increases in *Phalaris arundinacea* cover. The transient effect of the herbicide treatment on *P. arundinacea* on species cover shown in Figure 7 probably contributed to all those differences. Its influence may be judged by the not significant ($p > 0.05$) but roughly parallel drop with time for cover of non-*P. arundinacea* species in the seeded and control plots. Planting arrays were not associated with any additional statistically significant cover differences between years (Table 24 displays all such significant differences).

Species Richness and *P. arundinacea* Treatment. Herbicide application produced a persistent increase in species richness (Figure 9). Controlled burns produced no similar or distinct species richness effect.

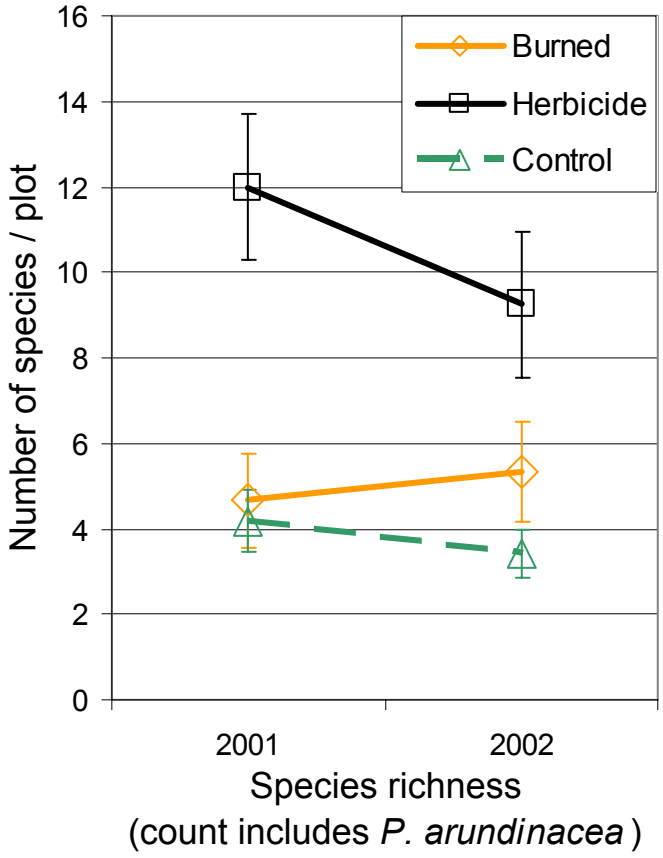

Figure 9.
Species richness, by *P. arundinacea* treatment.

Treatment and planting were in the spring of 2001. Species richness of canopy was recorded in August. Error bars are standard error of the mean.

Effect of *P. arundinacea* Treatment on Species Richness. Significantly greater 2001 species richness following herbicide on *Phalaris arundinacea* compared to burn and control treatment plots (257% and 288%, respectively, Tables 21 and 26) persisted into 2002, at 271% relative to the control plot value (Tables 22 and 26). The 2001 treatments produced no significant difference in species richness between control and burned plots, and burned plots were not significantly different from either of the other plot types by 2002 (Tables 21 and 22). Species richness did not change significantly within any *P. arundinacea* treatment plot type (Table 24).

Species Richness and Planting Array. Planting array produced transient differences in species richness. In Figure 10 the number of species planted into each array is indicated by dotted lines and small symbols without error bars.

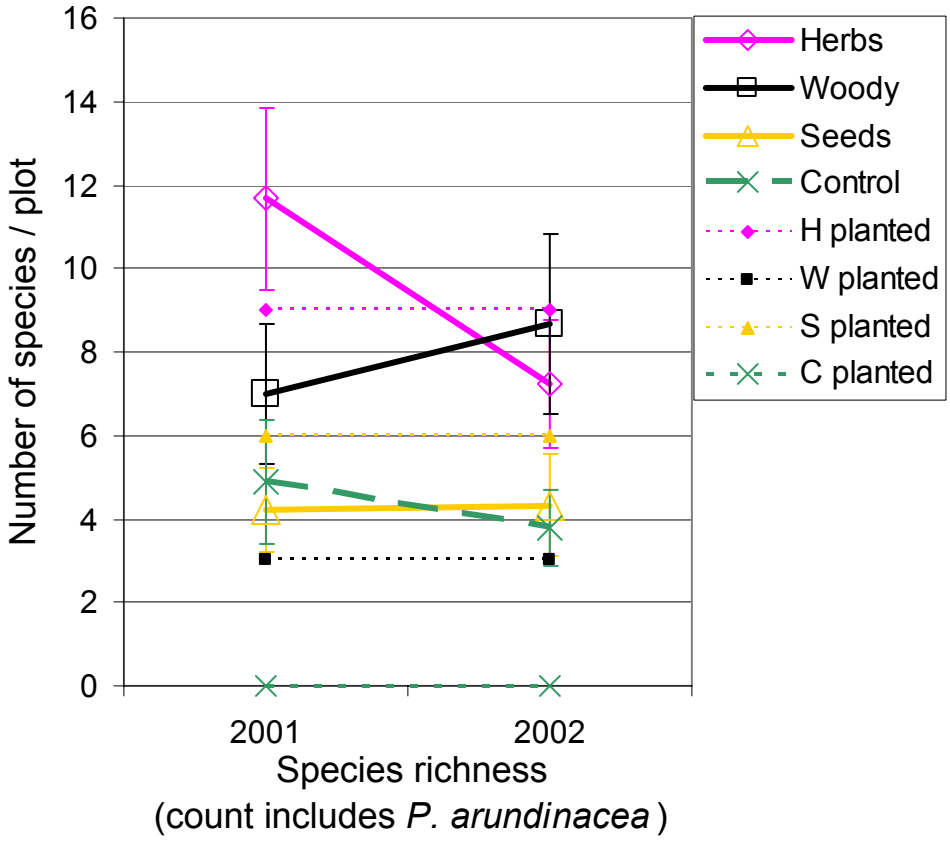

Figure 10.
Species richness, by planting array.

Planting was in the spring of 2001. Species richness in canopy was recorded in August.
Error bars are standard error of the mean.
Thin, dotted (not dashed) lines with small symbols indicate the number of species planted into each array.

For the control plots and two plot types receiving transplants (woody and herbaceous arrays) illustrated in Figure 10, the 2001 species richness was approximately four species over the number of species transplanted. For the plots given seeds, the average recorded species richness was roughly two species below the planted species richness (and well within the standard error of the mean for species

richness in the control plots) indicating relative failure of the attempt to establish an array of native species by seed.[17]

The herbaceous array plots had significantly greater species richness than the other three planting arrays (seed, control, and woody, 276%, 238%, and 166% of those values, respectively, Tables 21 and 26) in 2001. That is a reasonable consequence of more species having been planted into the plots planted with herbs (9) than the woody (3) or control (0) plots; for the plots sown with seeds of 6 species, it is consistent with failure of the attempt to establish a species array by seed. There were no other significant differences in species richness (Tables 21 - 23).

Changes in Planting Array Effect on Species Richness, 2001 to 2002. The 2002 drop in species richness (to 62% the 2001 value, Tables 24 and 26) in herbaceous array plots was the only significant species richness change. It may be attributed to the disappearance of annuals being reinforced by the cumulative failure of the five transplanted dicot species; note that the plots planted with herbs lost approximately five species' richness between years.

Differences within Herbaceous Array Response to *P. arundinacea* Treatment

An unexpected difference of survival for monocot and Dicot transplants was observed in the first season of growth following plot treatment and planting (2001). Survival and species richness among dicots was generally poorer than among monocots, even though more dicot species were planted (5 vs. 4, Table 2) Therefore, greater species richness among monocot transplants compared to dicot transplants can be attributed either to greater survival of monocots or greater visibility of monocots due

[17] The rough average of four volunteer species for individual plots should not be confused with a limit on species richness for any planting array or the plant establishment experiment as a whole. Most volunteer species were only found in a few plots, therefore contributing more to the general total for species

to herbivory on dicots. This difference was verified by three-way balanced ANOVA on cover and species richness data collected from the herbaceous array plots (Table 11). Additional analysis of factors used interaction mean square values as error man square values to calculate F and p values of terms relative to the interactions. No additional statistical significance ($p > 0.05$) was found for any term using this process. Tables 21 - 24 and 27 in Appendix C display statistical details used in the following analyses.

Table 11.
Cover and visible species richness of planted herbs

Three-way balanced ANOVA. Cover data was arc-sine-square-root transformed.
Abbrev: Year = Yr, *P. arundinacea* treatment = Tre, Monocot vs. Dicot = MvD.
Test error DF = 24. Factor breakdowns are in Appendix C, Tables 22 through 24.

		Cover of planted species				Species richness of planted herbs	
		Raw data		Transformed data		Raw data: no transformation needed	
Source	DF	F	P	F	P	F	P
Yr	1	5.73	0.025	10.05	0.004	2.63	0.093
Tre	2	7.27	0.003	6.35	0.006	0.16	0.692
MvD	1	4.99	0.035	7.23	0.013	6.45	0.018
Yr*Tre	2	1.74	0.197	0.19	0.827	0.48	0.623
Yr*MvD	1	0.64	0.433	0.08	0.779	3.77	0.038
Tre*MvD	2	6.73	0.005	8.38	0.002	0.16	0.692
Yr*Tre*MvD	2	0.85	0.441	0.09	0.916	1.12	0.341

Cover of transplanted monocots and dicots was not significantly different between plot treatments or between years. However, there were significant differences between cover for the control and herbicide treatments in 2002 (Table 22) and for cover and species richness in all comparisons of pooled monocot data with pooled dicot data (Tables 21 - 23).

richness than to the average species richness in individual plots. For an estimate of total volunteer species richness in the planted plots see Table 18, Appendix B.

Herbicide on *Phalaris arundinacea* improved the result of monocot transplantation (Figure 11). The effect persisted into 2002 despite that year's resurgence of *P. arundinacea* cover, which tended to conceal the transplants.

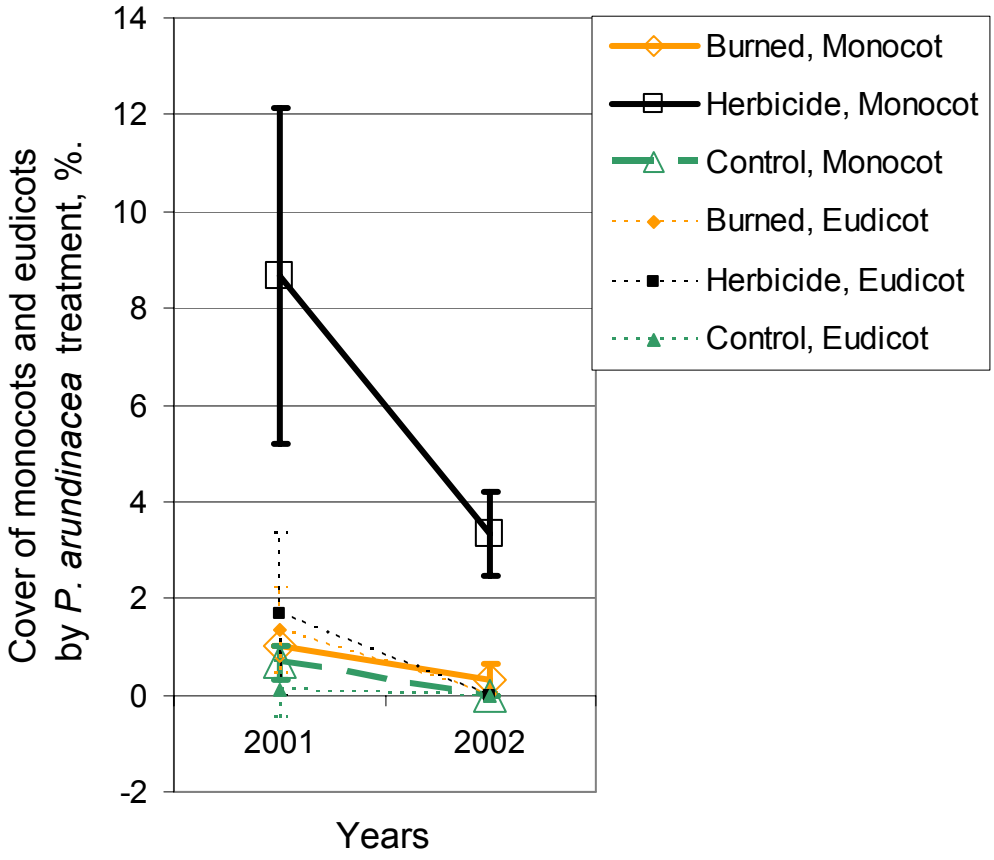

Figure 11.
Cover of herbaceous array, by treatment and botanical class.

Preparation and planting were in the spring of 2001. Cover was recorded in August.
All plots planted with herbs received the same numbers of each species.
Error bars are standard error of the mean. The lack of error bars for the burned monocot plots in 2001 and several plot types in 2002 indicates error ranges of 0. Total N = 9; N = 3 for each treatment type.

P. arundinacea Treatment Effect on Cover of Herbaceous Array. The pooled herbaceous array transplant cover (monocot + dicot) in 2002 was greater in the herbaceous array plots treated with herbicide (3.3%) than in the control plots (trace) (Table 221). There is a greater significance for both *Phalaris arundinacea* treatment

and treatment interactions with the monocot vs. dicot difference when the years are pooled (2001 + 2002, Table 11). For example, pooled year cover of monocots planted into *P. arundinacea* killed by herbicide was 718% the cover of dicots in the same plots (Table 27). The distinction between monocot and dicot cover was also significant in pooled years, planted monocot cover being 450% planted dicot cover (Tables 23 and 27).

Changes in *P. arundinacea* Treatment Effect on Herbaceous Array Cover.

Pooled monocot cover among *Phalaris arundinacea* treatments (total from within the herbaceous transplant array) decreased significantly to 36% its 2001 value by 2002 (Tables 23 and 27). Cover of the herbaceous transplants in general decreased significantly to 27% of the 2001 (Tables 11 and 27). No significant cover difference between years was found for monocots or dicots analyzed separately by any of the three *P. arundinacea* treatments, but monocot figures after herbicide do stand out in Figure 11.

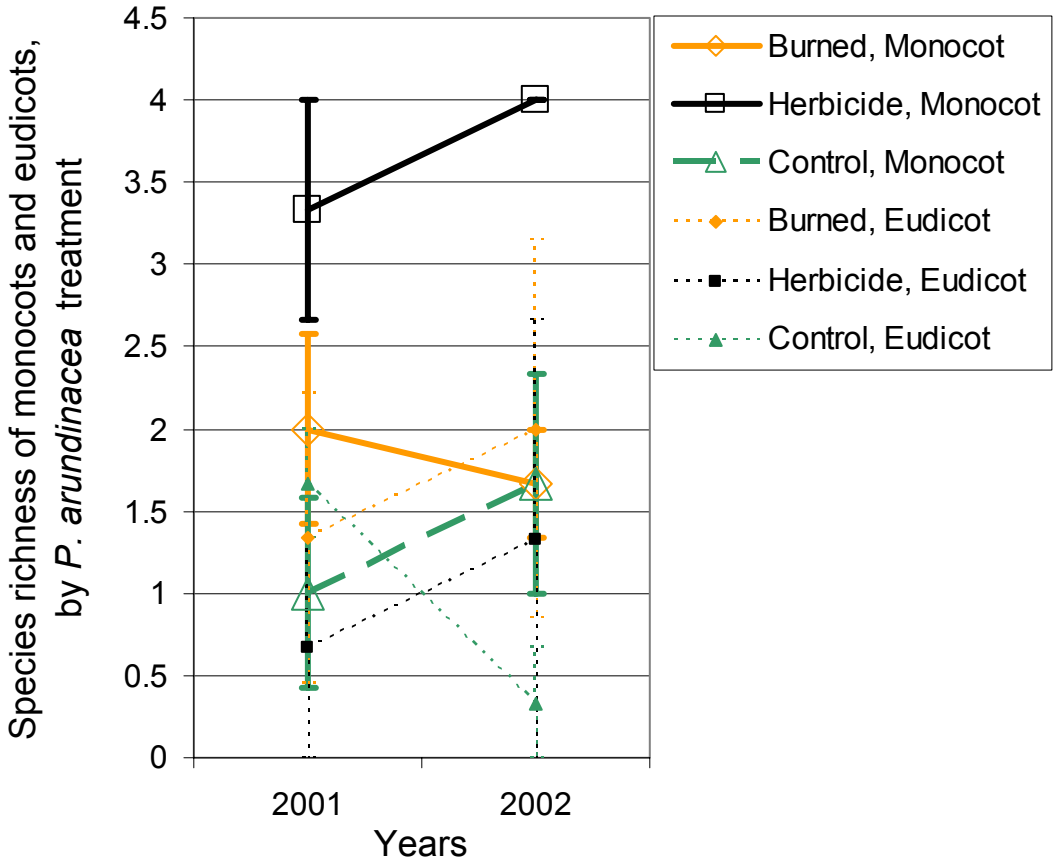

Figure 12.
Species richness of herbaceous array, by treatment and botanical class.

Preparation and planting were in the spring of 2001. Cover was recorded in August.
All plots planted with herbs received the same number of each species.
Error bars are standard error of the mean. The absence of error bars in 2002 for the plots treated with herbicide (in 2001) indicates an error range of 0. Total N = 9; N = 3 for each treatment type.

P. arundinacea Treatment Effect on Herbaceous Array Species Richness.

Among total herbaceous array plots combined, there was a significantly greater species richness of transplanted monocots than similarly transplanted dicots in 2002; 173% the general dicot value (Tables 22 and 27). For the years 2001 and 2002 pooled (Table 11), the monocot species richness was significantly 186% the dicot value (Table 27). In 2002 there was no error range for transplanted monocot species richness in the plots

prepared with herbicide, because all transplanted monocot species were visible in all such plots (Table 22).

Changes in Treatment Effect on Herbaceous Array Species Richness. In 2002, the total monocot transplant species richness increased significantly to 116% its 2001 value, while total dicot species richness was unchanged (Tables 11 and 27). The general transplanted monocot species richness actually increased with time (Figure 12) despite the concurrent drops in general species richness (Figures 9 and 10) and recovery of *Phalaris arundinacea* cover (Figure 7).

Eupatorium fistulosum as a Representative Dicot. In the herbaceous array plots, the cover sampling method lent itself to a "type 2" sampling error, loss of a genuine difference due to procedural flaws: In plots where *Phalaris arundinacea* was treated with herbicide, the low height of its cover in 2001 made species richness in those plots, and the rare dicot transplants in particular, relatively more visible than they were following other *P. arundinacea* treatments. *Eupatorium fistulosum* was an exception to this problem; as a tall and robust species, its surviving members were easily visible regardless of *P. arundinacea* cover and its fertile stalk numbers were recorded in 2001 and 2002. *Eupatorium fistulosum* was frost-sensitive and typically browsed where not sheltered by *Phalaris arundinacea*; it offers a representation of the principle of dicot failure in plots prepared with herbicide (Table 12, Figure 13).

Table 12.
Eupatorium fistulosum fertile stems in plots with and without herbicide

2001Kruskal-Wallis test results and basic statistics. Probability level is adjusted for ties.
No analysis of 2002 data produced results significant at $p \leq 0.05$.
Herbicide: Rodeo. Control & burned plots were combined to produce the category of no Rodeo herbicide.

		Blooming *E. fistulosum* stems/plot							
Herbicide	N	Maximum	Minimum	Mean	Median	Average rank	Z	DF	P
Yes	3	0	0	0.00	0.00	2.5	-1.94		
No	6	7	0	3.67	4.00	6.3	1.94		
Overall	9	7	0	2.89	0.00	5.0		1	0.042

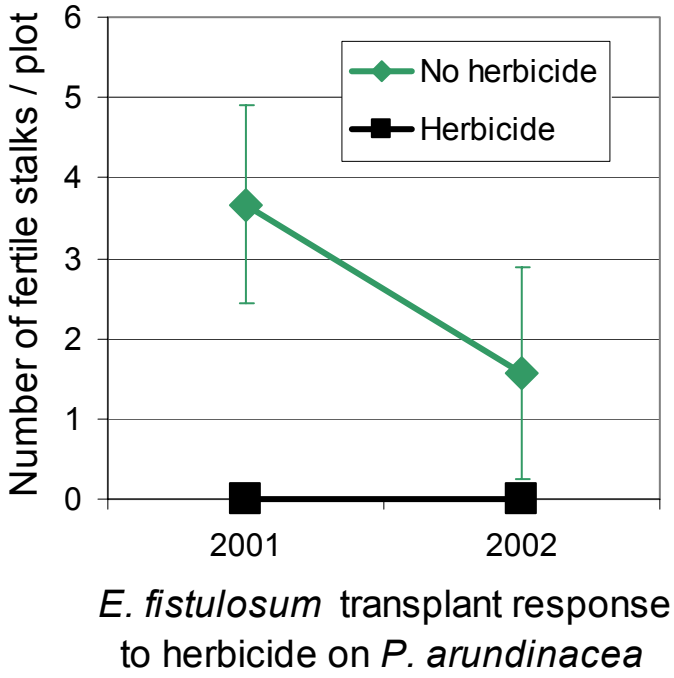

Figure 13.
E. fistulosum response to herbicide treatment of *P. arundinacea*.

Preparation and planting were in the spring of 2001. Fertile stalk numbers were recorded in August.
Error bars are standard error of the mean.
No fertile stalks of E. fistulosum were recorded in any plot prepared with herbicide

In 2001 the plots without herbicide, pooled, had significantly more fertile stems of *Eupatorium fistulosum* than plots treated with herbicide (Table 12, Figure 13). In 2002 there was no similar significance attributable to *Phalaris arundinacea* treatment.

The decline of numbers for fertile *Eupatorium fistulosum* stalks between 2001 and 2002 (Figure 13) corresponds to the general decline of dicots between those growing seasons. Though the Kruskal-Wallis test found a difference between Figure 13's plot treatment categories only in 2001, a Wilcoxon Signed Rank Test found no significant difference between years for either of those categories, at $p > 0.05$.

Hemiparasitic *Pedicularis lanceolata* as a Biological Control

Growth of the Hemiparasite

Most individuals of the hemiparasite *Pedicularis lanceolata* were not near maturity by the time of sampling, but they proved capable of growing with *Phalaris arundinacea* monocultures. Hemiparasitic haustorial attachments of *P. lanceolata*, as described by Piehl (1963, 1965) were found on roots of all the host species (*Clematis vriginiana*, *Juncus effusus*, *P. arundinacea* and *Scirpus cyperinus*).

Under the test conditions, competition by the other potential host species caused the strongest effect on *Phalaris arundinacea*. Regression of biomass figures indicated a non-linear effect attributable to *Pedicularis lanceolata* on total host biomass in a mixed host combination at $p < 0.05$, but not on the target species *P. arundinacea* alone.

Balanced ANOVA of the Experimental Design

Treatment Effect Within Host Systems. The source category of primary interest in Table 13 (compare with Table 4) is the host system and treatment interaction. This indicates no significant differences between the categories of hemiparasite *Pedicularis lanceolata* treatment and either of the control treatments (*Chelone glabra* seed or no seed) when the different host systems (*Phalaris arundinacea* alone or with the other host species) are taken into account. Because this ANOVA (Table 13) confirms the two host systems to be significantly different in effect, the two other treatment source categories that do not take host system into account (treatment alone and block with treatment) are not informative.

Competition Effect on *P. arundinacea*. The difference in *Phalaris arundinacea* aboveground biomass according to host system shows a valid and significant effect of competition upon that species, which was planted uniformly into both host systems. Only the difference between mixed-host containers and containers with *Phalaris*

arundinacea alone was a significant factor *P. arundinacea* aerial biomass (Table 13). There was no significant difference attributable to the randomized blocks.

The host systems themselves were originally different. The mixed host containers had twice as many plants, and four times as many species, as the *Phalaris arundinacea* monoculture system. For this reason, the significant difference between host systems in the columns of all host plants totaled (which pooled both host systems) is not informative. No interactions were significantly different from the error term, and no additional statistical significance ($p > 0.05$) was found for any term after additional analysis of factors with interaction mean square values used as error man square values to calculate F and p values of terms relative to the interactions. .

Table 13.
Host aerial biomass

Three-way balanced ANOVA. Block: used as error term in analysis. Test error DF = 10
Host systems: Either *P. arundinacea* alone, or 3 plants of *P. arundinacea* plus one plant from each of 3 native species (*Clematis vriginiana*, *Juncus effusus*, *Scirpus cyperinus*).
Treatment: *Pedicularis lanceolata* seed sown vs. two controls: *Chelone glabra* seed, or no seed.

		Phalaris arundinacea		Total, all host plants		
Source	DF	F	P	F	P	
Block (used as error term)	5	2.53	0.332	1.61	0.243	*
Host system	1	307.75	< 0.001	211.74	< 0.001	
Treatment	2	0.99	0.405	1.72	0.228	
Block*Host system	5	0.51	0.766	0.27	0.920	
Block*Treatment	10	1.22	0.380	0.58	0.802	
Host system *Treatment	2	0.16	0.855	1.37	0.299	

*F and p values of the total host plant block term were calculated by dividing the block mean square (86.22) by the total test error mean square (53.45) because Minitab returned an error message indicating a sum of squares value of 0.

Host System Effect on *Phalaris arundinacea*. *Phalaris arundinacea* grown alone had nearly twice the aboveground biomass of the same number of *P. arundinacea* individuals grown with an equal number of competing host plants (Figure 14). Total

aboveground biomass from the mixed host containers is shown for purposes of comparison. Note the lack of effects due to *Pedicularis lanceolata*.

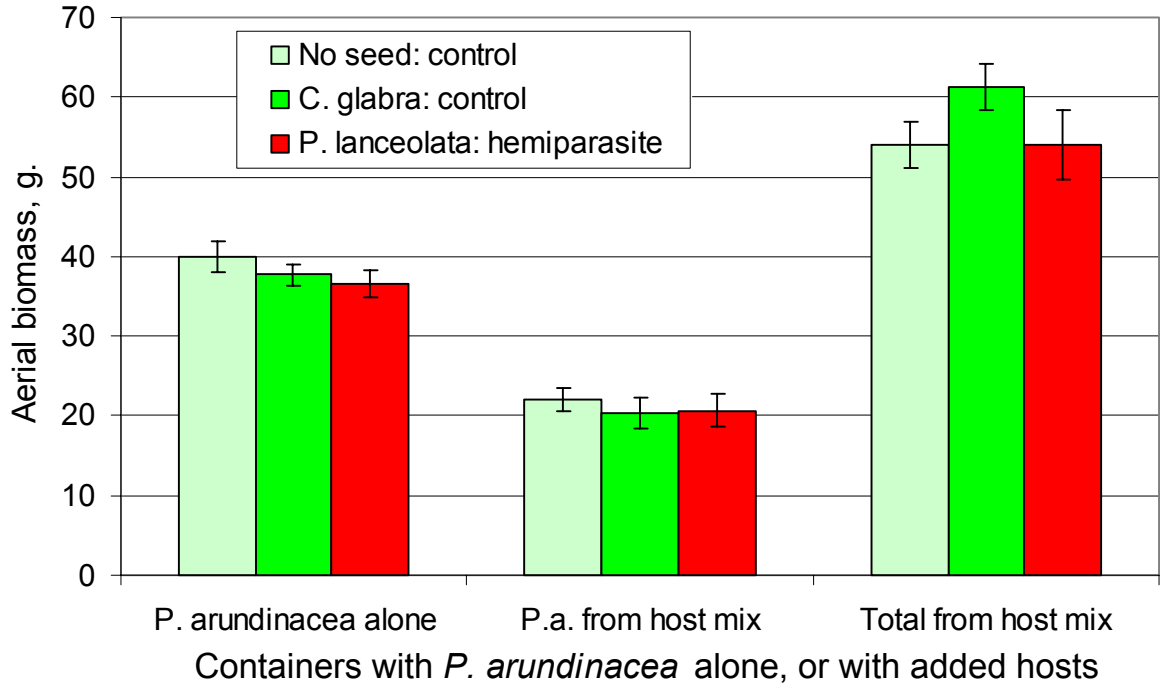

Figure 14.
P. arundinacea aerial biomass and competition from other host species.

Monoculture containers included only 3 plants of *Phalaris arundinacea*. Containers with mixed hosts included 3 plants of *Phalaris arundinacea*, plus one each of *Clematis virginiana*, *Juncus effusus*, and *Scirpus cyperinus*.
Error bars are standard error of the mean.

In mixed host containers the average aerial biomass of the *Phalaris arundinacea* plants (center bar group, Figure 14) was little more than half of the aerial biomass of *P. arundinacea* host plants grown alone (left group of bars). The effect of competition was much greater than the effect of the hemiparasite. Variation in shoot/root biomass allocation habits between species may account for the notably larger error bars in the category of total mixed host biomass (Figure 14). For much the same reason, the total aerial biomass of the mixed host containers is chiefly useful for comparisons of the hemiparasite's effects within that host category.

Regression of *Pedicularis lanceolata* and Host Biomass

Basic linear regression analysis was conducted between species because it allows entirely quantitative comparison, without the simplification of categorical grouping inherent to ANOVA. In this case, the biomass of both seeded species (*Pedicularis lanceolata* & *Chelone glabra*) was regressed with aerial host biomass. Only *P. lanceolata* produced significant effects on host species (Table 14). All correlation coefficients produced by analysis of host biomass relative to *P. lanceolata* biomass were negative. Similar regressions using *Chelone glabra* biomass revealed no similar significances and weaker, mixed correlation coefficients (Table 14). As there is no proof that the often small and sparse *P. lanceolata* plants in the mixed host containers established equivalent hemiparasitic relationships with all host plants of the same species, the individual species regressions within the mixed host treatment are included only to illustrate general trends.

Multiple tests showed no significant difference between *Pedicularis lanceolata* and *Chelone glabra* biomasses, though the means and medians were larger for *P. lanceolata* biomass than for *C. glabra* biomass (Table 28, Appendix C).

Table 14.
Host biomasses vs. biomasses of seeded species

Linear regressions, all sample counts = 6. *Pedicularis lanceolata*: hemiparasite. *Chelone glabra*: non-parasitic control sp.
The two host systems were: *Phalaris arundinacea* alone, or plus *Clematis virginiana*, *Juncus effusus*, and *Scirpus cyperinus*.
"Adj" abbreviates "adjusted" for r^2 values. Probability (p) values are from ANOVA accompanying the regression analysis.
Predictors (X axis) are total biomass; results (Y axis) are aerial biomass of the host species.

			Raw data			Transformed data		
Predictor	Result on:	Host system	Linear correlation coefficient (r)	Adj. r^2	P	Linear correlation coefficient (r)	Adj. r^2	P
P. lanceolata	*P. arundinacea*	*P. arundinacea*	-0.641	0.263	0.170	-0.706	0.374	0.116
		Host mix	-0.637	0.259	0.173	-0.592	0.189	0.215
	Total host	Host mix	-0.819	0.589	0.046	-0.888	0.735	0.018
	C. virginiana	Host mix	-0.739	0.432	0.093	-0.883	0.727	0.019
	J. effusus	Host mix	-0.492	0.052	0.322	-0.528	0.099	0.281
	S. cyperinus	Host mix	-0.485	0.044	0.330	-0.644	0.270	0.167
	Native host sum	Host mix	-0.680	0.328	0.137	-0.794	0.537	0.060
C. glabra	*P. arundinacea*	*P. arundinacea*	0.263	0.000	0.616	0.394	0.000	0.440
		Host mix	-0.089	0.000	0.868	-0.126	0.000	0.811
	Total host	Host mix	-0.105	0.000	0.843	0.105	0.000	0.846
	C. virginiana	Host mix	0 > -0.022	0.000	0.973	0.195	0.000	0.710
	J. effusus	Host mix	~ 0, < 0.022	0.000	0.991	0.148	0.000	0.781
	S. cyperinus	Host mix	0.094	0.000	0.862	-0.118	0.000	0.823
	Native host sum	Host mix	-0.045	0.000	0.941	0.164	0.000	0.755

Pedicularis lanceolata and Total Host Biomass. *P. lanceolata* had a significant effect on total host aerial biomass when biomass data from the mixed host containers was regressed alone (Extreme rightmost bar in Figure 14, also Table 14 and Figure 15).

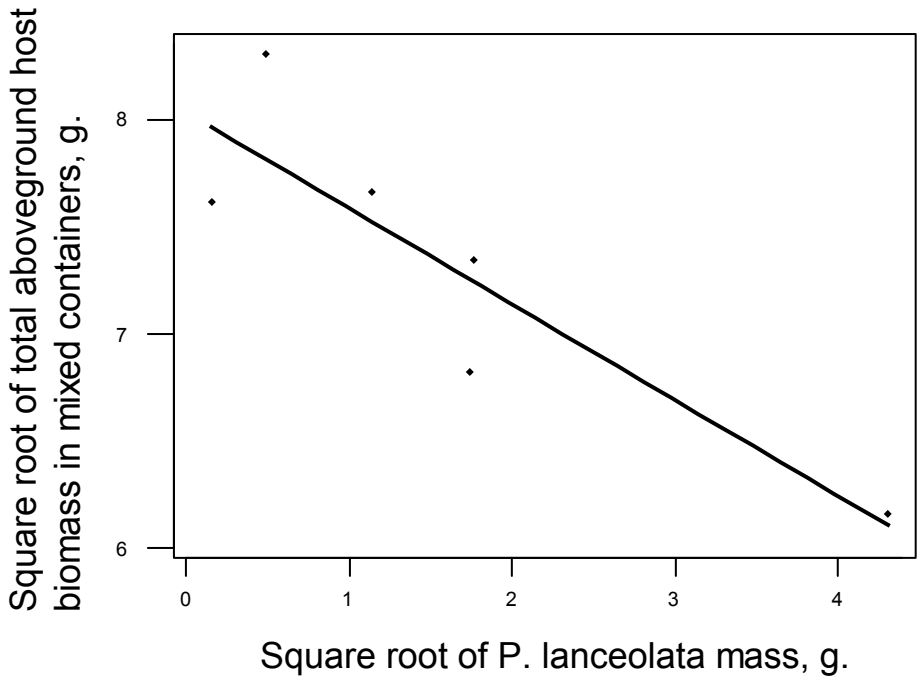

Figure 15.
Mixed container aerial biomass and *P. lanceolata* mass regression.

Y-axis= Total host aerial biomass, g
X-axis= *P. lanceolata* biomass, g
Regression p = 0.018, correlation coefficient (r) = -0.888 for transformed data. For raw data, p = 0.046, and correlation coefficient (r) = -0.819, implying that the relationship between *Pedicularis lanceolata* biomass and total host aerial biomass resembles a power function more closely than a linear one.

The container with the two most mature *Pedicularis lanceolata* individuals produced the extreme value for both maximum hemiparasite mass and minimum total host mass.

Development of the Experiment

Germination of the hemiparasite (*Pedicularis lanceolata*) and its counterpart control species (*Chelone glabra*[18]) planted as seed into the experimental containers was uneven. Only two plants of *P. lanceolata* emerged from the summer 2001 sowing, both in the same container, and no germination of *C. glabra* was found at all. That sowing was out of season because the host plants started from seed in the spring of 2001 needed time to establish root systems suitable for *P. lanceolata*[19]. The fall sowing of 2001 was the most successful. By the time the containers were removed from winter storage on 4 April 2002, *C. glabra* and *P. lanceolata* seedlings were emerging. The spring sowing of 2002 produced some seedlings, but their development was at least a month behind seedlings from the fall sowing. Seedling establishment failed entirely in two containers, one where *P. lanceolata* was intended, the other sown with *C. glabra*.

Soil in the containers did not have a consolidated structure. The containers were evidently dryer than intended. No gleying [dark or grayish soil hues] from saturated and anoxic conditions (Mitch and Gosselink 1993; Brady and Weil 2000) developed in more than a year. Roots penetrating to the bottom of all containers may have carried oxygen and removed water. Both activities would have prevented gleying. *Juncus effusus* and *Scirpus cyperinus* roots dropped steeply to the bottom of the containers, while *P. arundinacea* roots typically spread horizontally until striking the edge of a container and following it down. No dicot roots were observed to reach the bottom of the containers: those of *Clematis vriginiana* and *Pedicularis lanceolata* tended to branch shallowly,

[18] Germination tests of the nonparasitic control species *Chelone glabra* and culture of its shoots supported the assumption that control species is nonparasitc. *Chelone glabra* grows well from seed when potted alone with no possibility of a parasitic relationship. Its cuttings readily develop vigorous and independently effective root systems in soil or water and appear to thrive in either medium without hosts.
[19] *Juncus effusus* and *Scirpus cyperinus* seeds only germinated after exposure to intense sun, evidently requiring a combination of light and heat. Seedlings of *Clematis virginiana* and *Phalaris arundinacea* suffered some mortality in the unfertilized saturated milled peat of the starting flats until they were lightly fertilized and kept out of standing water. Treatment of *J. effusus* and *S. cyperinus* was changed similarly at the same time though they had not shown such problems with the potting medium. The two host species most sensitive to the milled peat conditions (*C. virginiana* and *P. arundinacea*) grew roots more shallowly in the test containers than the more peat-tolerant host species (*J. effusus* and *S. cyperinus*).

while *Chelone glabra* roots often followed the soil surface. Under container conditions, *Phalaris arundinacea* roots did not develop a mat and readily penetrated scattered pieces of clay. *Pedicularis lanceolata* roots and haustoria were generally within 20 cm of the soil surface, even for the largest hemiparasites. Though subterranean biomass was not recorded, shoot/root mass ratios for *P. arundinacea* were visibly less than one, the species' aerial structures having from 1/6 to 1/12 the bulk of its roots and rhizomes.

Host plants in all containers showed some evidence of nutrient shortage in 2002 (Brady and Wiel 2000), most commonly yellowing foliage indicative of nitrogen (N) shortage. Approximately half the plants of *Clematis virginiana* developed purple leaves in summer, a sign of phosphorus (P) shortage. At least two *C. virginiana* plants had leaves that turned black from the edges but did not fall even when completely dead and dry, distinctive of potassium (K) shortage. The *C. virginiana* in the same container as the two largest and oldest *Pedicularis lanceolata* plants turned completely black by late summer but developed more leaves after the two large hemiparasites in that container set seed and went dormant. Intensity of green color among *P. lanceolata* plants varied, particularly among the smaller specimens, but was generally a darker and more uniform green than among the host species or *Chelone glabra*. All sexual reproduction of *P. arundinacea* was in containers with no other host species. Foliage of the other host species generally grew taller than *P. arundinacea* in all mixed host containers, regardless of the presence of the hemiparasite. Watering the container soil from the top made it subject to nutrient loss by leaching (Partala, Mela, Esala, and Ketoja, 2001).

CHAPTER 4

DISCUSSION

Project Summary

Exposed or shallow consolidated subsoil resisted *Phalaris arundinacea* establishment. Areas of reduced *P. arundinacea* cover or biomass supported greater species richness. Soil characteristics correlated poorly with species richness, implying that species richness is limited by *P. arundinacea*. A *Phalaris arundinacea* shoot/root ratio of 1/4 to 1/8 implies low fertility of the project area. Evident low nutrient levels in the Orchard Bog project area are promising for native species richness reestablishment. Areas of *P. arundinacea* predominance contracted slightly during this study.

Among *Phalaris arundinacea* treatments, the herbicide Rodeo caused was the most effective, with its subsequent results differing for monocot and dicot transplants. The monocots used were more successful after *P. arundinacea* foliage was killed, while dicots showed the opposite reaction. *P. arundinacea* litter and root mat layers are barriers to seed growth, even where its foliage is removed. Competition with other native perennial species reduced *Phalaris arundinacea* aboveground biomass by 40% after two growing seasons in a low-nutrient medium. The root hemiparasite *Pedicularis lanceolata* was able to parasitize *P. arundinacea* but established slowly and showed significant effect only on total biomass of a host species combination.

None of the control methods tested is a panacea for *Phalaris arundinacea*, but various methods offer degrees of control and produce different results. Some procedures enhance the effects of each other when combined, as did herbicide treatments with monocot transplanting.

Soil Conditions and *Phalaris arundinacea* Growth

Summary

Out of 10 soil properties analyzed by ordinal logistic regression, structure was the only property that significantly predicted *Phalaris arundinacea* cover. The effect of pH was dubious, and the significance of nutrients (nitrogen, N, and phosphorus, P) was sensitive to how nitrogen data was analyzed. Water content, hydrology, soil texture, and organic matter content were not significantly correlated with *P. arundinacea* cover. Knowing the conditions favoring *P. arundinacea* relative to conditions favoring species richness allows focused *P. arundinacea* control.

Soil Structure

Phalaris arundinacea had the greatest cover on loose soil. Consolidated subsoil was associated with low levels (≤ ~ 25%) or a complete absence of *P. arundinacea* cover. Maurer and Zedler (2002) found that while nutrient level affected *P. arundinacea* establishment it had less effect on mature plants. They found no significant correlation between any other soil properties and *P. arundinacea* growth but did not report consolidated subsoil. This study of established *P. arundinacea* found no significant predictive value for any soil property except consolidated subsoil.

Examination of site conditions gives some indication of a cause and effect relationship in the correlation of consolidated subsoil and *Phalaris arundinacea* cover. In one case, the consolidated soil condition arose or persisted despite *P. arundinacea* cover (Table 6). This example shows that *P. arundinacea* does not necessarily lead to soil structure development in the Orchard Bog area: it did not cause that soil to develop structure and may well have allowed it to lose what artificial structure it had. Under a root and rhizome mat (> 10 cm), the mineral soil in that area was a mass of visible fragments evidently reconsolidated after cultivation.

Phalaris arundinacea added structure to soil in a test conducted under different conditions: unconsolidated sediments allowed to dry from drainage and transpiration, with structure and permeability as goals (Löser 2002). Orchard Bog area subsoil is consolidated and its texture (Table 6) is a mixture of particle sizes, leading to low pore space because small masses of minute particles pack between larger particles (Brady and Weil 2000). In soils with minimal pore space, capillary action can exclude air meters above a water table (Hunt, Walker, and Krabbenhoft, 1999). *Phalaris arundinacea*'s tendency to grow roots and rhizomes above, not in, saturated soil (Lefor 1987; Galatowitsch and others 1999) may be relevant to the fact that such soil appears to have regained a consolidated structure under a *P. arundinacea* monoculture.

Regressions confirmed the expected negative relationship between *Phalaris arundinacea* cover and species richness (Figure 3), but did not show a significant relationship between species richness and either soil structure or nutrient levels (Table 8, Figure 4). *P. arundinacea* cover correlated significantly with soil structure (Table 5), but plant species richness did not correlate significantly with soil structure (Table 8), suggesting that the relationship between plant species richness and soil properties is not direct. Orchard Bog area species richness shows no clear bias for consolidated soils, and a dubious bias for low pH (Figure 4). Instead, *P. arundinacea* appears to affect species richness by excluding other plant species from topsoil (Table 5, Figures 16 and 17). While species richness is not necessarily the same as species quality or conservation value, most of the species from areas of transect species richness were native, and can be considered an improvement over *Phalaris arundinacea* monoculture (Table 17, Appendix C).

Although *P. arundinacea* was did not predominate on the sloping ditch banks in Figure 17, the species is not inhibited by slope alone (Odland 2002), it grows on banks of both Locust Knob Branch and Beaverdam Creek that are steeper than any part of the

transects used in this study (Figures 1, 16 and 17). *P. arundinacea* is planted for erosion control (Lefor 1987; Green and Galatowitsch 2001).

Key to Figures 16 and 17:

Water:

Consolidated subsoil:

Loose soil:

Mixed soil:

Phalaris arundinacea:

Smaller native plants resembling fen vegetation:

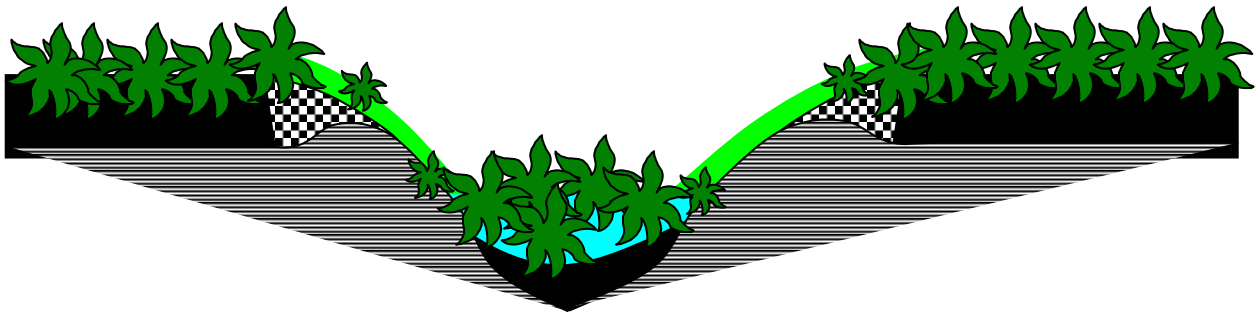

Figure 16.
Approximate profile of transects 1, 2, and 3.

Not to scale.

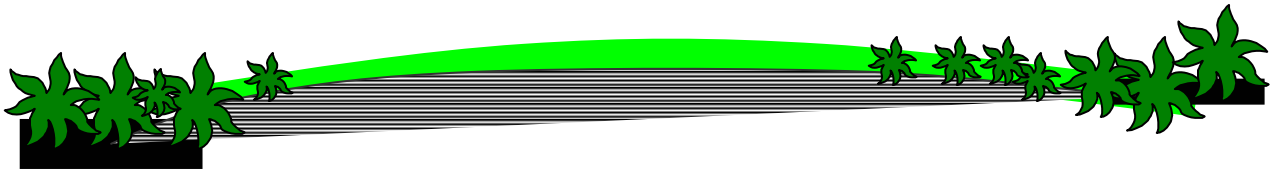

Figure 17.
Approximate profile of transect 4.

Not to scale.

Phalaris arundinacea can invade fens if herbaceous canopy removal exposes the ground surface (Lindig-Cisneros and Zedler 2002). Areas of exposed subsoil that persistently resist *P. arundinacea* establishment demonstrate that this is not the case in the Orchard Bog project; subsoil is colonized by *Salix*, *Carex*, *Scirpus*, *Eleocharis*, or *Sparganium* species. Silt deposits tracing old ditch channels in excavated pools support isolated strips of *P. arundinacea*, similar to Figure 16. Transect 4's center and the top of an earthen dam have no *P. arundinacea* cover despite years of exposure. In those examples, neither various moisture levels nor disturbance by heavy equipment led to establishment of *P. arundinacea* cover on Shady Valley subsoil.

Phalaris arundinacea may be able to persist on, or spread onto, Orchard Bog subsoil once established. A subsidy effect from resource exchange can allow clones of *P. arundinacea* to expand into poor habitat. Such reproduction exacerbates *P. arundinacea*'s aggressive habits (Maurer and Zedler 2002). In the Orchard Bog project area *P. arundinacea* stems extend over soil where they do not root. Deposition of a litter layer may eventually allow root and rhizome growth. Expansion of *P. arundinacea* on the transects may derive from extension of rhizomes through a layer of litter or moss.

Phalaris arundinacea Habits and Habitat

Nutrients. Multiple sources positively correlate *Phalaris arundinacea* growth with fertility (Apfelbaum and Sams 1987, Šrůtek 1993, Straškrabová and Pratch 1998, Wetzel and van der Valk 1999, Green and Galatowitsch 2001, 2002). Wetzel and van der Valk (1999) found that it was a dominant species at all fertility levels they tested, but Green and Galatowitsch (2002) reported it to be more of a problem at higher fertility levels. While low nutrient levels inhibit *P. arundinacea* establishment, they have less (or a less rapid) effect on mature plants (Maurer and Zedler 2002).

Soil fertility may affect *Phalaris arundinacea* growth. Phosphorus (P) and nitrogen (N) (as nitrate, NO_3^-) were generally at low levels in this study. Some factor

other than soil structure affects *P. arundinacea* cover, or all points with loose soil structure would have supported the same cover. Fertility, like loose soil structure, is characteristic of topsoil (Brady and Weil 2000). When different species compete for the same limiting resource, the species most efficient at low levels of that resource eventually displaces other species (Tilman and Pacala 1993). Efficient fen species are typically sedges and mosses, not grasses (Grootjans and van Diggelen 1995).

The analysis summarized in Table 5 treated nitrogen (N, detected in the form of nitrate, NO_3^-) as a categorical variable; either detectable or not (John Kalbfleisch, ETSU, personal communication). Use of that principle for ordinal logistic regression (Table 5) did not reveal macronutrients (N and phosphorus, P) to be significant predictors of *Phalaris arundinacea* cover, but the regression process was sensitive to the form of nitrogen data. A similar ordinal logistic regression using nitrogen data in continuous form gave both phosphorus and nitrogen (from NO_3^-) levels as significant predictors of *P. arundinacea* cover (Table 29, Appendix C). The second regression is not intended to cast doubt on the statistical process used in this study, but it does imply that a more sensitive nitrogen test, or one on other available forms of that element (Gambrell and Patrick 1978; Mitch and Gosselink 1993), could have indicated macronutrient levels to be significant predictors of *P. arundinacea* cover by allowing nitrogen to be tested as a continuous variable. Because nitrogen and phosphorus abundance, like lose soil structure, are topsoil qualities (Brady and Weil 2000) significance of nitrogen and phosphorus as predictors would not have changed this study's conclusion that the distinction between Orchard Bog area topsoil and subsoil affected *P arundinacea*.

Significance of macronutrient levels as predictors of *Phalaris arundinacea* cover would have been consistent with observations supporting a role for nutrients in plant community dynamics at the Orchard Bog project: 1) General yellowing during the growing season; a symptom of various possible stress factors, including N limitation

(Brady and Weil 2000). 2) *Alnus serrulata* was the main exception to the yellowing; all *Alnus* sp. associate with N-fixing organisms (Voss 1985). 3) Plants were greener near some carrion, and the relative heights of species were reversed: *Symphyotrichum puniceum* and *Solidago* sp. were taller than *P. arundinacea*; all were taller than *Scirpus cyperinus*. Meters away relative heights were opposite, with *S. cyperinus* tallest, *Solidago* sp. and *S. puniceum* smallest. Decaying animal matter is a rich nitrogen source (Begon, Harper, and Townsend, 1996) and tall herbs are characteristic of fertile fens, short herbs of infertile ones (Wheeler and Shaw 1991). 4) *Schizachyrium scoparium*, found in the Orchard Bog project (Tables 15 and 17, Appendix C), is a superior competitor on low-nutrient sites and typical of stable, nutrient-limited habitats (Tilman and Wedin 1991).

Phalaris arundinacea colonizes and grows under conditions of nutrient deposition (Klopatek 1978). The shifting hydrology to be expected of *P. arundinacea* habitat (Linden, Clapp, and Gilley, 1981; Šrůtek 1993; Straškrabová and Pratch 1998; Barnes 1999; Morrison and Molofsky 1998, 1999; Galatowitsch and others 1999; Kilbride and Paveglio 1999) tends to carry nutrients and oxygen, increasing fertility (Mitsch and Gosselink 1993). Excess fertility particularly disturbs fen habitats (Marrs 1993; Beltman, van der Broek, Bloemen, and Witsel, 1996; Brülisauer and Klötzli 1998; Patzelt and others 2001; Tallowin and Smith 2001; Drexler and Bedford 2002).

It is likely that nitrogen levels have changed in the Orchard Bog area since the wetland project began. Soil nitrogen tends to be less available under saturated conditions. The nitrogen compound this study tested for, nitrate (NO_3^-), is the first form lost (Gambrell and Patrick 1978; Mitch and Gosselink 1993; Bedford 1999). It is logical that such denitrification is reducing fertility levels in the Orchard Bog project area. Nitrogen limitation may explain why areas of *P. arundinacea* predominance are yellowing and contracting in the Orchard Bog project. If so, any consequent species shift has been slow.

pH. The pH range found in Orchard Bog project soil (Figure 2 and Table 6) is at the low extreme for fens such as Orchard Bog (Mitsch and Gosselink 1993; Beltman and others 1996; Thormann, Szumigalski, and Bayley, 1999; Tallowin, Kirkham, Smith, and Mountford, 1998). Wheeler (1995) reports that pH is not always well correlated with plant species and community structure in fens. *Phalaris arundinacea* field studies report conditions from basic (Moyle 1945, Klopatek 1978; Maurer and Zedler 2002), to pH ~ 4, with fertilization (Levesque and Malthur 1983, Van Duren and others 1998). *P. arundinacea* tolerates a wide range of pH, if fertility is adequate. This is consistent with the dubious role of pH as an influence on *Phalaris arundinacea* in this study and with a potential role for nutrient concentration. Indications that low pH is often associated with low conservation quality of fens (Grootjans and van Diggelen 1995; Beltman and others 1996; van Duren and others 1998), verifies the dubious nature of the correlation of low pH with native plant species richness near Orchard Bog (Figure 4) though low pH may occur in the early stages of formation for some fens (Lode 1999).

Soil Moisture. Floodplains are *Phalaris arundinacea* habitat (Laasimer 1965, in Estonian, cited in Truus and Tõnisson 1998; Šrůtek 1993; Straškrabová and Pratch 1998; Barnes 1999). *Phalaris arundinacea* tolerates or prefers shifting water levels, with constant or frequent drainage, over consistent flooding (Klopatek 1978; Linden and others 1981; Morrison and Molofsky 1998, 1999; Barnes 1999; Galatowitsch and others 1999; Kilbride and Paveglio 1999; Odland 2002) and can dominate other species at different water levels (Wetzel and van der Valk 1999). *Phalaris arundinacea* roots avoid constantly wet soil (Lefor 1987; Galatowitsch and others 1999), and for a wetland plant *P. arundinacea* is sensitive to reducing conditions (Brix and Sorrell 1996).

Root mats such as those of *Phalaris arundinacea* are a common adaptation to saturated soil (Mitsch and Gosselink 1993) and areas of sediment shifts, erosion, and deposition (Sun, Cai, and An, 2002). *Phalaris arundinacea* transports less oxygen to its

roots than other wetland plants. Such transport requires energy and is most effective if roots are concentrated (Steinberg and Coonrod 1994) and the species preferentially puts its energy into growth (Wetzel and van der Valk 1999), consistent with growth of a root mat as an adaptation to anoxic soil. Because extra production of subterranean biomass is a metabolic cost to a plant, and not efficient in low-nutrient environments (Tilman and Wedin 1991), anoxic soil probably exacerbates the effect of stress from low nutrient levels on *P. arundinacea*, by making the grass shift its resources to production of an inefficient root mat.

Implications for Control of *Phalaris arundinacea*

Subsoil exposure produced areas of increased species richness where *Phalaris arundinacea* was inhibited. Infertile habitats of short sedge and bryophyte cover similar to the ditch slopes of Figure 16 are useful refuges for rare and sensitive species (Wheeler and Shaw 1991; van Wirdum 1993; Grootjans and van Diggelen 1995; Thormann and others 1999; Amon and others 2002; Drexler and Bedford 2002). Topsoil removal is recommended to improve species recovery both in fens and where *P. arundinacea* is a problem (van Wirdum 1993; Wheeler 1995; Beltman and others 1996; Brülisauer and Klötzli 1998; Kilbride and Paveglio 1999; Klötzli and Grootjans 2001; Patzelt and others 2001; Tallowin and Smith 2001), particularly when topsoil removal exposes mineral soil (Brülisauer and Klötzli 1998; van Duren and others 1998; Lode 1999). Subsoil exposure can restore fens by reducing fertility and lowering the soil surface to the water table (van Wirdum 1993; Brülisauer and Klötzli 1998; Patzelt and others 2001). For example, *Sphagnum* moss needs constant moisture (Price and Whitehead 2001).

Fens are wetlands fed by reliable groundwater sources that keep the water table high and stable (van Wirdum 1993; Grootjans & van Diggelen 1995; Wheeler 1995; van Duren and others 1998; Lode 1999; Patzelt and others 2001; Amon and others 2002;

Godwin, Shallenberger, Leopold, and Bedford, 2002; Papazisimou, Bouzinos, Christanis, Tzedakis, and Kalaitzidis, 2002). The constant water levels vital to fens tend to reduce the availability of N (Marrs 1993; Mitsch and Gosselink 1993; Beltman and others 1996; Brülisauer and Klötzli 1998; Patzelt and others 2001; Tallowin and Smith 2001), conditions which differ from the *Phalaris arundinacea* habitat already described as fertile with varying water levels.

Topsoil removal may be useful to create small, isolated pools to increase topographic diversity in the Orchard Bog project; which now lacks the hollows that once supported local species richness (Barclay 1957). Site diversity and hollows are important for wetland species diversity (Tryon and Herman 1991; van Wirdum 1993; Lode 1999; Price and Whitehead 2001; Drexler and Bedford 2002). Pools with subsoil bottoms, previously constructed for the Orchard Bog wetland project, apparently only support *Phalaris arundinacea* where sediments remain from original route of ditches. (Such sediments also support the only examples of *Typha* sp. in the project. *Sparganium* plants following old ditch routes through pools are a distinctly darker green and about twice the height (above average water level) than neighboring *Sparganium*.)

Native Plant Establishment in *Phalaris arundinacea*

Summary.

- Reduction of *Phalaris arundinacea* monoculture cover and biomass by herbicide facilitated the establishment of robust native plant species. Biomass reduction unexpectedly persisted through two growing seasons.
- Early-season burns were ineffective to reduce *P. arundinacea* cover and biomass or facilitate the establishment of robust native plant species.
- Robust native plants, once established in *P. arundinacea* monocultures, were able to compete with *P. arundinacea* and increase species richness.
- The relative height advantage of woody plants did not make them effective competitors to cause differences in *P. arundinacea* cover and biomass.

Effect of *Phalaris arundinacea* Treatments

Herbicide. Although *Phalaris arundinacea* cover reestablished itself after herbicide (Figure 7), a common response (Apfelbaum and Sams 1987; Kilbride and Paveglio 1999; Pizzo and Schroeder 2001), its biomass was still in the process of recovery two growing seasons after treatment (Figure 6). Herbicide control of *P. arundinacea* is most effective before the plants produce seed (Pizzo and Schroeder 2001). Biomass figures were not reported by any of the *P. arundinacea* herbicide references found.

Herbicide reduced *P. arundinacea* biomass for two growing seasons (Figure 6) and increased species richness (Figure 9), though the tendencies were toward return to control values. *P. arundinacea*'s dense canopy tends to deprive small plants of light, preventing their growth (Wheeler and Shaw 1991; Straškrabová and Pratch 1998; Barnes 1999; Wetzel and van der Valk 1999). Canopy removal by herbicide allowed germination of volunteer species; in combination with planting the effect of herbicide persisted.

Green and Galatowitsch (2002) reported subterranean biomass of *Phalaris arundinacea* at less than 2/3 of its aboveground biomass, in contrast to the roughly 8 to 1 ratio of subterranean over aerial biomass in the Orchard Bog area for the first sampling after herbicide treatment. *P. arundinacea* adapts to low nutrient levels by shifting its biomass allocation underground (Wetzel and van der Valk 1999; Green and Galatowitsch 2001, 2002; Maurer and Zedler 2002). The proportionally large subterranean biomass allocation of *P. arundinacea* following herbicide implies low fertility levels, which evidently rose in the second year.

Begon and others (1996) explain a process to account for the implied shifts in fertility: Plant residues tend to absorb N as they commence decay, releasing it when decay is complete. The *P. arundinacea* killed by herbicide in the spring of 2001 would have absorbed N as it began to decay, releasing N later. Reduced amounts of litter in 2002 (Figure 6) would have absorbed little of the N released then. The level of N release in herbicide-treated plots should follow 2002 litter levels and decrease in 2003, so *P. arundinacea* subterranean biomass allocation should increase in response.

Controlled Burns. Fire was probably historically rare in the wetlands of Shady Valley, judging the original forest canopy (Barclay 1957). Controlled burns did not have a significant direct effect on *Phalaris arundinacea* biomass or cover values (Figures 6 and 7), as also reported by Apfelbaum and Sams (1987). Timing affects the effect of fire on *P. arundinacea*: early fires stimulate it; later fires inhibit it but can harm desirable warm-season species (Henderson 1990). Orchard Bog area litter levels were reduced by fire (Figure 6), followed by germination of seeds and establishment of seedlings. *P. arundinacea* litter inhibits germination and establishment of other species (Straškrabová and Pratch 1998), but so does the species' canopy, which recovered rapidly from fire.

Phalaris arundinacea biomass allocation was evidently affected by burning of the litter. Average subterranean *P. arundinacea* biomass for control plots increased

between 2001 and 2002 (Figure 6), evidently in reaction to decreasing fertility as already described. The burned plots had less litter to absorb nitrogen, and showed no such allocation shift (Figure 6 and Table 24, Appendix C). This difference in significance is consistent with the shoot/root ratio difference between burn and control treatments in transformed 2002 data (Table 9). As the litter layer in burned plots continues to recover, it should absorb nitrogen, reduce fertility, and increase *P. arundinacea* subterranean biomass allocation there.

Effect of Planting

The proportional cover relationship between *Phalaris arundinacea* and other species was significantly affected by planting for one growing season. Species richness was significantly affected for at least two growing seasons (Table 10, Figures 7 - 10). Closure of the *P. arundinacea* canopy in 2002 after herbicide and mortality of dicot transplants are sources for the general increases in *P. arundinacea* cover (Table 10). It is possible that the dicot species planted were relict species from the initiation of the Orchard Bog project, and that these species are not able to maintain their cover under the new conditions of denitrification, soil saturation, etc. that followed establishment of the preserve and partial filling of the Locust Knob Branch ditch.

Both the cover and species richness of transplants were highest where the most plants and species were planted (Figures 8 and 10). Species richness is not necessarily the same as species quality or conservation value, but the species planted in the experiment were all native, as were most of the volunteer species (Table 18, Appendix C). Such a community can be considered an improvement over *Phalaris arundinacea* monoculture.

The herbaceous array produced different responses according to the botanical class of transplant (monocot vs. dicot), in interaction with treatment (Table 11, Figure 11). Despite the recovery of *Phalaris arundinacea* being most noticeable following

herbicide (Figure 7), herbaceous array transplants following herbicide on *P. arundinacea* showed a significant increase in cover of non-*P. arundinacea* species relative to control plots two growing seasons after planting (Figure 11) and an increase in species richness for transplanted monocot species (Figure 12). In contrast, the representative dicot *Eupatorium fistulosum* failed entirely following herbicide on *P. arundinacea* (Figure 13). The evident bias of monocots for plots without *Phalaris arundinacea* cover may be attributed to effects from competition from the established monoculture, for example, the leaf orientation of *Phalaris arundinacea* makes it a superior competitor for light compared to most other monocots (Wetzel and van der Valk 1999). The reaction of dicots is evidently less direct, an effect of shelter from frost and herbivory provided by *Phalaris arundinacea* cover. Dicot transplants may be indifferent to established grass cover in the absence of herbivory (Brown and Bugg 2001).

It appears that herbivores in *Phalaris arundinacea* preferred this study's dicot transplants as forage. *P. arundinacea* is evidently not preferred forage for wildlife (Straškrabová and Pratch 1998; Barnes 1999; Howe, Brown, and Zorn-Arnold, 2002), neither were the *Scirpus* and *Carex* genera transplanted (as also described by Pandit and Fotedar, 1982). *Juncus effusus* in Shady Valley is avoided by cattle even when all other vegetation (presumably including the aforementioned *Scirpus* and *Carex* sp.) is grazed to cm of the ground. Herbivory was the main cause of mortality for transplants of the dicot blue vervain (*Verbena hastata*) in *P. arundinacea* (Rachich and Reader 1999).

By 2002 monocot transplants (*Carex vulpinoidea* and *Juncus effusus*) seemed able to exclude *Phalaris arundinacea* seedlings from the ground area under their foliage. *Phalaris arundinacea* seedlings near those transplants were subject to competition by two sources: the older transplanted monocots and surrounding *P. arundinacea* seedlings. *Phalaris arundinacea* is unable to invade tussocks of other

species (Werner and Zedler 2002), and can be sensitive to competition, especially for light (Jones and others 1988; Morrison and Molofsky 1998; Werner and Zedler 2002).

The woody species array showed a significant shift in cover for one growing season and was the only planted array to increase average species richness from 2001 to 2002, but its cover did not increase as expected. The woody transplants suffered high mortality by the end of the second growing season. Many of the remaining woody transplants, both dead and alive, were girdled by rodents.

The seed array showed no significant differences from control conditions. Some of that lack of effect may have been due to timing; seeds of many native plant species need exposure to winter to cue them when it is spring. Seeds in this study were sown after *Phalaris arundinacea* cover was reduced in spring. By the time exposure to winter allowed those seeds to become active, the *P. arundinacea* cover had largely reestablished itself.

Water Table and *Phalaris arundinacea*

Ground water levels in the *Phalaris arundinacea* monoculture plot areas responded to precipitation levels and did not stay consistently near the surface (Figure 5). As pointed out, common or preferred habitat of *P. arundinacea* is subject to varying water levels but fen habitat of good quality has a steady water table. The existence of *P. arundinacea*'s preferred hydraulic conditions is a likely factor contributing to the existence of its monocultures. Shifting water levels also accelerate decay and nutrient release (Mitsch and Gosselink 1993: van Duren and others 1998) and *P. arundinacea* becomes established most easily at high nutrient levels (Maurer and Zedler 2002).

Distinct and structurally intact remnants of the *Phalaris arundinacea* litter layer are embedded in its root mats. These fragments and the pieces of litter composing them, though decayed, are often too large to have penetrated the root mat while retaining their structure, implying that the penetration was of roots into the litter layer

and that the mats may form by invasion of a saturated litter layer by roots and rhizomes. The root mats of *P. arundinacea* near Orchard Bog may have grown after the wetland project raised the water table.

Control of *Phalaris arundinacea*

Seed burial under the *Phalaris arundinacea* root mat interferes with recovery of species richness. All methods for removal of the root mat and litter layer have drawbacks associated with them. Burning results vary. It can cause habitat shifts that either decrease species richness (Sluis 2002) or improve it (Tryon and Herman 1991). With herbicide, fire can allow seed germination while the *Phalaris arundinacea* canopy is gone (Pizzo and Schroeder 2001), but burning can also eliminate woody plants (such as *Vaccinium macrocarpon* & *Spiraea alba*) from wetlands (Tryon and Herman 1991; Clark and Wilson 2002; Kirkman, Goebel, West, Drew, and Palik, 2002). Plowing can break up a litter layer, but plowing alone exacerbates *P. arundinacea* as a problem species (Apfelbaum and Sams 1987). Disking or sod removal combined with both herbicide and dry weather worked to control *P. arundinacea* for Kilbride and Paveglio (1999). Herbicide is most useful when the preferred species have a longer dormant season than the target species (Kilbride and Paveglio 1999; Pizzo and Schroeder 2001). Desirable native species in the Orchard Bog area have longer growing seasons than *P. arundinacea*, for example *Juncus effusus* and *Vaccinium macrocarpon*. All such combined treatments are potentially destructive and should be applied with extreme caution to proven monocultures or loci of *P. arundinacea* invasion, as demonstrated by Pizzo and Schroeder (2001).

A consistently high water table should inhibit *Phalaris arundinacea* both directly (Kilbride and Paveglio 1999) and by fertility reduction. *P. arundinacea* already shows signs of nutrient stress (poor foliage color and preferential biomass allocation to roots) in the Orchard Bog area. Rhizome production is metabolically expensive for plants, and

of limited use in low-nutrient environments (Tilman and Wedin 1991). The local retreat of *P. arundinacea* areas of predominance may be a gradual manifestation of a nutrient limitation effect.

Species Establishment.

Species capable of persisting are the key to restoration of species richness (Sluis 2002). The crux to increasing species richness is to find species that persist after planting. Lindig-Cisneros and Zedler (2002) recommended establishment of native species to prevent *Phalaris arundinacea* invasion. Species richness is difficult to establish once *P. arundinacea* has developed its cover, litter layer, and root mat. Judging by the nature of volunteer species in treated plots, there is a relic source of native plant species richness preserved in a dormant seed bank under *P. arundinacea* monocultures in the Orchard Bog Project. The seed bank appeared to vary in nature from place to place, as described by van der Valk and Davis (1978). Seed banks, dormant seeds and propagules in the soil, are important assets to species richness and the vegetation community of a wetland (van der Valk and Davis 1978; Mitsch and Gosselink 1993; van Duren and others 1998; Rossell and Wells 1999; Combroux, Bornettte, and Amosand, 2002).

Eupatorium perfoliatum and *Vernonia noveboracensis* would have been better choices for dicot *Phalaris arundinacea* competitors in the Orchard Bog area. *Spiraea alba* and saplings of *Alnus serrulata* appear resistant to frost, browsing, and rodent damage. Some Orchard Bog area vines grow on *Phalaris arundinacea*: *Clematis virginiana*, hedge bindweed (*Calystegia sepium*), and hog peanut (*Amphicarpaea bracteata*), which has robust seeds evidently able to establish in *P. arundinacea*. Using nitrogen-fixing species such as *A. bracteata* or *Alnus* sp. as rivals for a species that may be fertility-dependant is questionable (Tallowin and Smith 2001) and depends on local conditions and project goals.

As a wetland restoration cover *Scirpus cyperinus* is compatible with native species richness and is "excellent" shelter for wildlife (Larson 1999). It competes effectively with *Phalaris arundinacea* in the Orchard Bog area, as do two large, scarce, but relatively shade-tolerant sedge species: *Carex lupulina* and *Carex gynandra* (Voss 1972; Strausbaugh and Core 1977; Gleason and Cronquist 1991). Leafy bulrush (*Scirpus polyphyllus*), the robust, clonally spreading Virginia chain fern (*Woodwardia virginica*), and large grasses of the genus *Glyceria* are other local Shady Valley prospects as *P. arundinacea* competitors[20]. *Glyceria striata* is preventative of *P. arundinacea* (Lindig-Cisneros and Zedler 2002).

Marsh fern (*Thelypteris palustris*) and sensitive fern (*Onoclea sensibils*) can survive under an aggressive wetland species (Morrison 2002). They do so near Orchard Bog, but are too short to overshadow *Phalaris arundinacea*. Bracken (*Pteridium* sp.) is taller and spreading locally among *P. arundinacea*. *Pteridium* sp. and *Woodwardia virginica* are promisingly adaptable, large, clonal ferns for *P. arundinacea* competitors[21] (fern data are from Lellinger, 1985).

[20] Where they are native, *Carex crinata*, *Carex mitchelliana*, and *Carex gigantea* could also be useful.
[21] As is ostrich fern (*Matteuccia struthiopteris*) in partial shade and its native range north of TN.

Hemiparasitic *Pedicularis lanceolata* as a Biological Control

Summary.

Results of *Pedicularis lanceolata* effects on *Phalaris arundinacea* must be considered preliminary. While the ability of *Pedicularis lanceolata* to parasitize *Phalaris arundinacea* was confirmed, the relationship did not demonstrably reduce *P. arundinacea* biomass or facilitate growth of native plant species by removal of a botanical barrier (as described by Johnstone, 1986). There was no evidence that *P. arundinacea* is a preferred host for *P. lanceolata*.

The fact that effects of *Pedicularis lanceolata* on host species are more strongly significant after square-root transformation of the data implies that the relationship between hemiparasite and hosts is not linear. *Pedicularis lanceolata* may affect larger plants more, suggesting an equalizing effect that could aid species richness by favoring small plants.

Container Conditions and Species Interactions

Non-parasitic competition on *Phalaris arundinacea* was the strongest effect discovered (Table 13, Figure 14). *P. arundinacea* is affected by competition, as already discussed. Two of the three alternate host species (*Juncus effusus* and *Scirpus cyperinus*) in the mixed host containers have the early growth habits recommended by Maurer and Zedler (2002) for competition with *P. arundinacea*.

In the first year (2001) *Phalaris arundinacea* appeared to compete effectively with its companion hosts, similar to results by Wetzel and van der Valk (1999), but those authors do not mention continuing their test to a second growing season. Early in 2002 *P. arundinacea* growth became stunted in association with the other host species, presumably by competition for nutrients.

Pedicularis lanceolata Effects

There is evidently a significant effect of *Pedicularis lanceolata* on cumulative host biomass (Figure 16). The fact that this regression of hemiparasite biomass with aerial host biomass was more strongly significant after square-root transformation (Table 14) implies a non-linear relationship between hemiparasite and host biomass.

Lackney (1981) demonstrated that *Pedicularis lanceolata* is an obligate hemiparasite unable to grow or survive without a host. Therefore, its survival when accompanied only by *Phalaris arundinacea* confirms its ability to use that species as a host. Among individual species tested (Table 14), *P. arundinacea* aerial biomass did not show the strongest correlation with *P. lanceolata* biomass. *P. lanceolata* does not have the strictly limited effect on the target species that is ideal for a biological control (Begon et al 1996; Strong and Pemberton 2000), but that fact was known in advance (Piehl 1965).

It is likely that the immaturity of *Pedicularis lanceolata* plants limited the power of the experiment. *P. lanceolata* seedlings were often small, few, and scattered at the time of sampling and so not in equal proximity to all host plants within a container. The three largest *P. lanceolata* plants all grew in mixed host containers. It is not known whether the mixed host combinations contributed to the vigor of the *P. lanceolata* plants exposed to them by the different host species available, the greater density of host plants available (6 plants instead of 3), or both effects, or neither.

The root mat typical of *Phalaris arundinacea* in Shady Valley did not form in the containers. The unsaturated container soil and the young age of the test plants could both have contributed to the lack of root mat development. It is possible that the generally shallowly-rooted *Pedicularis lanceolata* may have a different effect on *P. arundinacea*, and on *P. arundinacea* relative to other, more deeply-rooted host species, when the target host species' roots are concentrated in a shallow mat.

Pedicularis lanceolata Characteristics

Pedicularis lanceolata seeds typically establish poorly, and it is not a pest because it does not survive agricultural conditions (grazing, plowing, mowing, herbicide, etc.). *P. lanceolata* is described as “competition sensitive, [it] will not compete and declines or dies with weedy species and exotics” (UMES 2003). Poor seed establishment was observed in the container tests, but vulnerability to aggressive species was absent, probably because the host plants were limited by low nutrient levels. The hemiparasite was able to survive and grow in association with *Phalaris arundinacea* and may have had its greatest effect on *Clematis virginiana*, a fast-growing vine.

Introduction of alien biological control species is the usual cause of difficulty with the principle of biological control (Strong and Pemberton 2000). *Pedicularis lanceolata* is not alien but native, with state conservation statuses ranging from “special concern" (CT) through “threatened” (NY, TN) and “endangered” (MD, MA, PA) to “historical” (extirpated from KY) (USDA 2003). These classifications contribute to making its introduction to Shady Valley as a part of *Phalaris arundinacea* control policy worth further investigation.

Implications for Control of *Phalaris arundinacea*

Considering its slow effect, *Pedicularis lanceolata* might be more suited to stabilization of species richness than treatment for an established *Phalaris arundinacea* monoculture. It is doubtful that *P. lanceolata* is capable of establishing from seed in untreated *P. arundinacea* monocultures. *P. lanceolata* may establish in such monocultures under low-nutrient conditions after some pretreatment combination disrupts the *P. arundinacea* canopy and litter layer, or it might be transplanted in plugs with various innocuous host species (Piehl 1965). Establishment of *P. lanceolata* in *P. arundinacea* monocultures would at least double plant species richness there.

Wetlands need plant species richness to recover native animal species richness (Pandit and Fotedar 1982; Wheeler 1995). The root hemiparasite's non-linear effect on host plants implies that it may be compatible with the low-growing swards typical of species-rich fens, and it is unlikely to hinder the growth of desirable rootless plant species such as mosses.

Pedicularis lanceolata 's possibly greater effect on *Clematis virginiana*, the only dicot host, should be investigated because *P. lanceolata* may prefer dicot hosts and could contribute to their decline if planted with the intention of controlling *P. arundinacea*. Or, since *C. virginiana* was the host species that most visibly exhibited signs of nutrient stress, plant species with high nutrient requirements may be more vulnerable to *P. lanceolata* under conditions of nutrient limitation.

CHAPTER 5

RECOMMENDATIONS

The Orchard Bog Project Area

Control efforts on *Phalaris arundinacea* need not be restricted to a single treatment or approach. Multiple treatments could control *P. arundinacea* by cumulative stress when used in combination. Such a holistic approach is often necessary for wetland habitat restoration (Wheeler 1995).

Biological Conditions.

Transplants. Some species, particularly those with the best resistance to browsing, survive and increase in *Phalaris arundinacea* under conditions typical of the Orchard Bog preserve. Because areas of species richness appear to gradually expand at the expense of *P. arundinacea* in the Orchard Bog area, creation of more areas of species richness is recommended. Transplanting is labor-intensive but effective with the correct choice of species. Transplant quality, survival, and diversity could be increased by nursery culture before planting.

Recommended local species for transplanting into the Orchard Bog area as robust competitors for *Phalaris arundinacea* include the dicots *Eupatorium perfoliatum* and *Vernonia noveboracensis*, the monocots *Scirpus cyperinus*, *Scirpus polyphyllus, Carex lupulina*, *Carex gynandra, Glyceria striata* and any other large, local *Glyceria* sp., and the clonal ferns *Woodwardia virginica* or (for slightly dryer sites) *Pteridium* sp. The conditions favorable to different transplant types should be kept in mind. Complete removal of *P. arundinacea* cover by herbicide appears to favor monocot transplants, while dicots often need the protection from frost and herbivory afforded by some form of monocot cover. Dicots, particularly persistent and clonal woody species, may be the best choice to transplant into areas where *Phalaris arundinacea* grows intermixed with

other species and general destruction of plant cover by herbicide or plowing is not an option. Dicots could also be considered for high ground or fertile sites. Some native dicots may be more sensitive to nutrient levels than many native monocots.

Provisional competitor species for *Phalaris arundinacea* include the vines *Calystegia sepium*, *Clematis virginiana* and *Amphicarpaea bracteata*, and the shrub or small tree *Alnus serrulata*. *Spiraea alba* is a provisional transplant, depending on production of seedlings from the local population. Tryon andHerman (1991) mention alder, willow, and maple as undesirable in habitat resembling the Orchard Bog area but point out that woody cover provides useful pockets of shelter and habitat diversity. An established canopy of woody plants should effectively compete for light with *Phalaris arundinacea*, which is not dominant under woodland conditions (Paine and Ribic 2002). Woody cover, including evergreen trees, originally predominated in Shady Valley (Barclay 1957) and can be considered a valid cover type there. Choosing species resistant to rodent damage would improve the effectiveness of a woody species array.

Seed Establishment. Because the seed establishment procedures tested in this study were not significantly effective, repetition of the same procedures is not recommended. *Phalaris arundinacea* cover removal alone is likely to be followed by *P. arundinacea* seedlings but sowing seeds of other species would be easier than transplanting, if it worked. Fall seed sowing after fire and followed by herbicide in early spring could be a better prospect than spring sowing of dormant seeds. Fall herbicide might be applied first and the dead foliage burned after drying, but the most active and vulnerable time of *P. arundinacea*'s life cycle is spring. *Phalaris arundinacea* treatment could also be conducted without sowing additional seeds. A relic of native plant species diversity appears to exist as a buried seed bank.

Inorganic Site Conditions.

Water level. The current water retention practice in the Orchard Bog area should be maintained without producing any abrupt shift in water level, particularly avoiding any decline. Decline of the current water table could exacerbate the established *Phalaris arundinacea*, a species which tends to do best in areas of varying hydrology. Meanwhile, many of the relic areas of native species richness are on ditch slopes, where sudden flooding would drown them.

Nutrient Level. Though this study did not find a conclusive association between established *Phalaris arundinacea* and soil fertility, soil fertility is known to enhance establishment of new *P. arundinacea* plants. Nutrients are a drawback for species richness in wetland habitat and appear to increase the ability of *P. arundinacea* to exclude other species. Preservation of the Orchard Bog watershed is recommended to keep more nutrients from washing into the project area. Preservation of any native vegetation resembling buffer strips along tributaries feeding the Orchard Bog Project should be encouraged, as should construction of more buffer strips. Wooded buffer strips improve water quality while preventing *P. arundinacea* dominance (Paine and Ribic 2002). Any impoundments and wetlands capable of collecting or absorbing sediment and nutrients before they reach the Orchard Bog Project area should be preserved.

Soil Modification. It is recommended that any further disturbance of soil in the Orchard Bog Project area should involve exposure of the local subsoil, to prevent recolonization by *Phalaris arundinacea* or other aggressive species. Judging by current conditions, such subsoil exposure in the Orchard Bog area produces a plant community superior to *P. arundinacea* monoculture. It is not known whether this difference derives solely from structural properties of the subsoil, which probably resists circulation of air

and water and may resist penetration by rhizomes of species such as *P. arundinacea* or *Typha* sp. that depend on rhizomes, or if the subsoil's structural properties interact with its low fertility to exclude aggressive species. The fertility and rhizome penetration issues could use further investigation, but the significant correlation of Orchard Bog area subsoil with *P. arundinacea* inhibition is established.

Phalaris arundinacea Beyond Orchard Bog

Prevention seems to be the best method for dealing with *Phalaris arundinacea*. For future projects, it would definitely be a good idea to establish a cover of native species before making any changes (such as water level rise) that might exacerbate a potential *Phalaris arundinacea* problem. Seeds would definitely be better prospects before that root mat develops. The process of *Phalaris arundinacea* root mat formation and its practical limits as an adaptive strategy could use investigation.

Knowing *Phalaris arundinacea*'s habitat preferences allows better planning and assessment of situations where it is likely to be troublesome, a useful policy guide for future projects outside Shady Valley. The grass is most likely to be a problem on fertile, fresh sediments subject to temporary flooding, particularly flooding in cold weather. Where consolidated subsoil is available, *P. arundinacea* control may be relatively simple. In areas where there is a market for topsoil, subsoil exposure could even be profitable[22].

Monitoring and Further Investigation

Continued monitoring of *Phalaris arundinacea* predominance and extent around the areas of shallow subsoil not invaded would help judge local trends and provide a standard for comparison. Nutrient deprivation is likely to cause a persistent stress on *P.*

[22] *P. arundinacea* does not tolerate repetitive mowing well (Jones and others 1988), so would not be a problem weed in lawns.

arundinacea in the Orchard Bog project, facilitating the other control methods. Development of the plots planted in 2001 should be watched. Cover surveys would be simple to repeat annually. Biomass collection could be repeated late in the growing season of 2003 to investigate long-term reactions of *Phalaris arundinacea* to the end of burning, and in another few years to check for persistent effects of herbicide. Long-term monitoring is advised for wetland creation and restoration projects (Mitsch and others 1998; van Duren and others 1998).

Continue to test native plant establishment. Various combined treatments could be tested, for example, herbicide combined with fire or disking (both of which would require dry weather), in *Phalaris arundinacea* monoculture areas[23] to stimulate any remaining seed bank. Try to find a combination or timing of treatments to allow establishment of native plants by seed. Coordinated treatments, such as spring and fall burns to remove as much litter as possible, with a fall herbicide treatment to allow root mat decay by spring, could give good results. Keep in mind that some combinations are not compatible, for example woody plant establishment with burning, or perennial evergreen establishment with herbicide. Woody vegetation may be desirable for historical reasons because it is known to have originally predominated in Shady Valley (Barclay 1957). The main flaw for the woody array tested in this study appears to be that it used easily-cloned species that were incidentally susceptible to rodent damage.

This study did not test seed bank viability, but the amount and nature of volunteer species appearing in the experimental plots implies that a seed bank exists. Seed banks expire (van der Valk and Davis 1978, Brülisauer and Klötzli 1998, van der Hoek and Braakhekke 1998, Bakker and Berendse 1999, Galatowitsch and others 1999).

[23] Seek areas of *Phalaris arundinacea* monoculture bordering the lower (northerly) reaches of the ditch shown in Figure 1. The NW side of Locust Knob Branch also has scattered areas of monoculture. Considering the subsidy effect that can support remote clones of *P. arundinacea* in unfavorable locations, the 3 m radius (6 m diameter) plots were probably about the right size, though they seemed excessively difficult to prepare and plant at the time.

Investigation of seed bank conditions should be a priority because the value of any relic native seed bank in the Orchard Bog area is constantly decreasing.

Alive or dead, the thick *Phalaris arundinacea* root mat is likely to resist ignition and inhibit germination of any original seed bank beneath it. Where the *P. arundinacea* cover, root mat, and litter layer are simultaneously removed, a seed bank could become active. Repeated and well-timed applications of herbicide can shift *P. arundinacea* cover to an ecologically preferable cover of native annual species (Kilbride and Paveglio 1999; Pizzo and Schroeder 2001). That is one cover alternative, and could be used in small areas to produce diversity of habitat, but general establishment of long-season perennials would be incompatible with routine herbicide application. Perennial seed establishment and rescue of a relic seed bank would require a briefer or more selective treatment to be effective. Soil disturbance and sod removal are risky where *P. arundinacea* is involved, but could be tried in areas of exclusive and confirmed monoculture where it is unlikely to make conditions worse, particularly following herbicide and if the weather is dry (Kilbride and Paveglio 1999).

Hemiparasitic *Pedicularis lanceolata* as a Biological Control

The test described in this research ended prematurely. The hemiparasite should have at least two growing seasons, preferably three, before examination of its effect. Any similar container test should attempt to stimulate *Phalaris arundinacea* to form the root mats typical of its growth in the Orchard Bog area. Less container drainage than was allowed in this study, combined with litter accumulation and a gradual water level increase, might work. An infertile soil mixture with loose, light structure would facilitate subterranean biomass collection.

Before any field use, *Pedicularis lanceolata* should be tested using host mixtures combining *P. arundinacea* with species of interest in Shady Valley, such as *Vaccinium macrocarpon* and *Spiraea alba*. It should also be tested with *P. arundinacea* alone, to

determine if its effect on that species can be severe enough to facilitate establishment of seeds in such monocultures. The hemiparasite would be most useful if it has its greatest effect on large host plants, which could make it a general facilitator of plant species richness.

Field tests could investigate methods of establishing the *Pedicularis lanceolata* in *Phalaris arundinacea* monocultures, its effect on mixed plant communities, and its vulnerability to herbivores. Any field tests of *Pedicularis lanceolata* on *P. arundinacea* need not be carried out near high-quality habitat or in Shady Valley.

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APPENDICES

APPENDIX A
SCHEMATIC FOR PLANTED PLOTS

Table 15.
Guide to plot numbers

Plots identified by number, *P. arundinacea* treatment, and planting array. For use with Figure 18.

	Plant arrays & plot numbers			
Treatment of *P. arundinacea*	Woody transplants	Herbaceous transplants	Control	Herbaceous seeds
Controlled burn	1	10	19	28
Controlled burn	2	11	20	29
Controlled burn	3	12	21	30
Rodeo herbicide	4	13	22	31
Rodeo herbicide	5	14	23	32
Rodeo herbicide	6	15	24	33
None	7	16	25	34
None	8	17	26	35
None	9	18	27	36

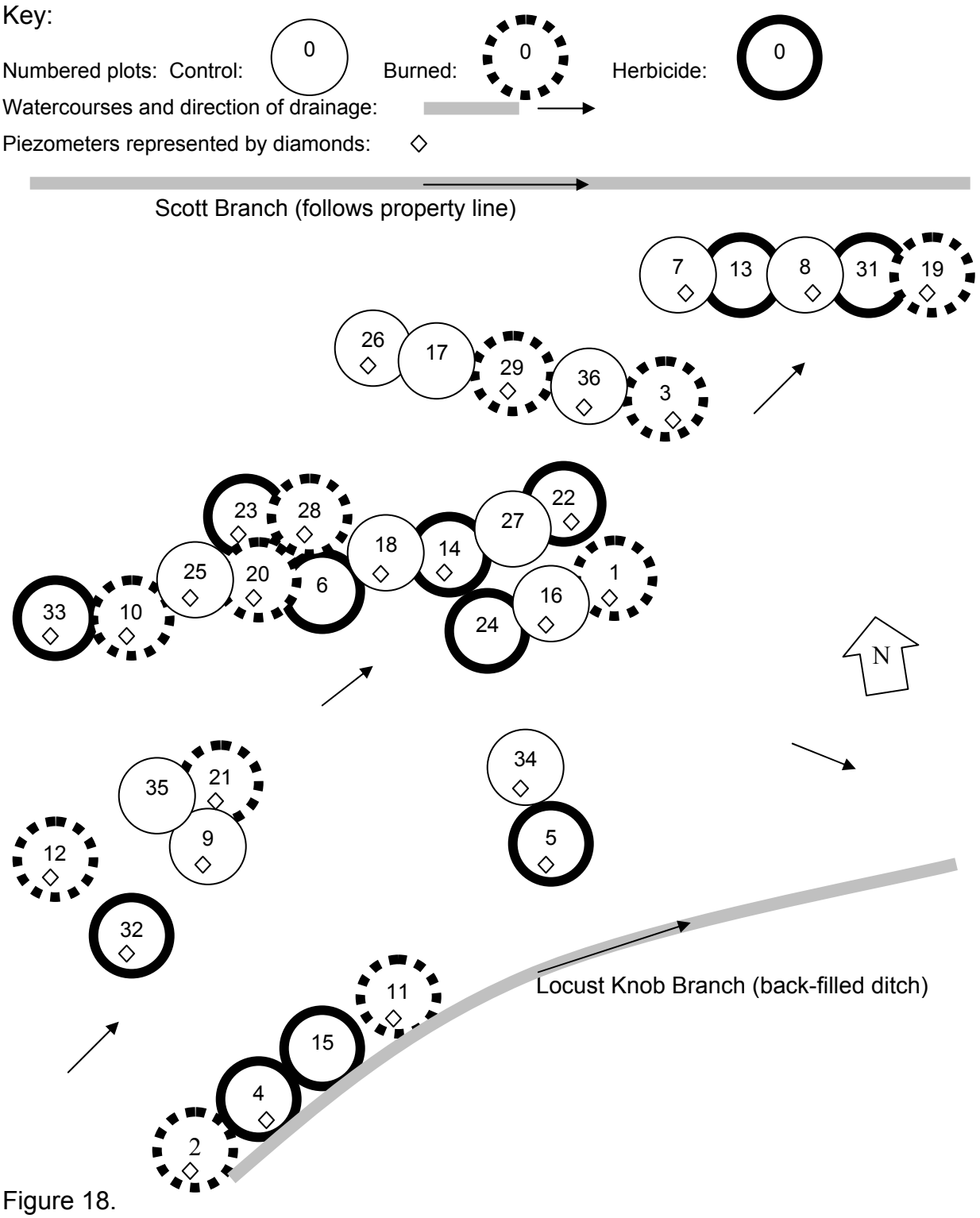

Figure 18.
Schematic for native plant establishment test plots

Not to scale; plot sizes exaggerated and piezometers displaced from plot centers for legibility of numbers.
Plot numbers are correlated with planting arrays in Table 19.
Plot # 30 is SSW of this diagram (Figure 1).

APPENDIX B

SPECIES LISTS FOR THE ORCHARD BOG PROJECT AREA

This appendix is organized into four sections. The first section is dedicated to specimens of the Gramineae (grasses) collected in Shady Valley and archived in the John C. Warden Herbarium, East Tennessee State University. The second section concerns other monocots, particularly cryptic species that are not graminoids, similarly collected and archived in the John C. Warden Herbarium. Neither set of specimens was originally collected for herbarium use; any flaws in condition should not be attributed to the herbarium. The third section reports species identified during transect species inventory. The fourth section reports unplanted species identified in the planted plots in 2001 and 2002. Voucher specimens were not collected from the transects or plots except when they are included within the first two sections.

The project reported in this thesis required determination of species richness. Exact species identification was attempted but not required or accomplished. Many specimens were immature or out of season for identification to the species level, others were members of difficult genera requiring expertise beyond the author's ability.

Gramineae from the Orchard Bog Project Area, 2001

Identification of these Gramineae is assumed accurate to the genus level. The order is alphabetical by genus. Specimens are from the Orchard Bog area unless otherwise specified.

Table 16.
Graminoid species identification

(Table 16 occupies pages 120 through 122, alphabetically by genus)

Genus, species Family Common name	Location description	Collection date
Agrostis sp. (cf. *alba* L.) Poaceae Redtop?	Marshy area	Aug. 3, 2001
Agrostis sp. (cf. *hyemalis* Walter) Poaceae (Small?) bent-grass	Moist subsoil, ditch slope, Root mat under red maple above last dam,	June 15, 2001, July 22, 2001
Agrostis sp. (cf. *perennans*, *altissima* [rare] Walter) Poaceae (Autumn? Coastal bog?) bent-grass	Ditch, mud upstream of earthen dam	July 7, 2001
Bromus sp. (cf. *inermis* Leysser) Poaceae Brome-grass	Southern end, between large tobacco shed, stream, & pasture	June 19, 2001
Dactylis glomerata L. Poaceae Orchard-grass	Under pecan tree, lawn of abandoned house at Quarry Bog wetland area entry	July 22, 2001
Dichanthelium clandestinum L. Poaceae Deer-tongue witch-grass	Widely distributed on disturbed, wet soil	Sept. 2, 2001
Dichanthelium commutatum Schultes Poaceae Variable witch-grass	Widely distributed on exposed, moist soil	July 31, 2001
Echinochola crusgalli L. Poaceae Barnyard-grass	Center of gravel drive	Aug 3, 2001, Aug 14, 2001
Eragrostis sp. (cf. *multicaulis* Steud.) Poaceae Lovegrass	Center of gravel drive.	Aug 3, 2001
Festuca elatior L. Poaceae Meadow fescue KY 31	Under pecan tree in lawn of abandoned house at Quarry Bog area entry, gravel in front of storage shed, Orchard Bog	July 22, 2001 Sept. 2, 2001

(Table 16 occupies pages 120 through 122, alphabetically by genus)

Genus, species Family Common name	Location description	Collection date
Glyceria sp. (cf. *grandis* S.) Poaceae American manna-grass	Southern end, wooded wetland by large tobacco shed	Aug. 18, 2001
Glyceria sp. (cf. *striata* Lam.) Poaceae (Fowl?) manna-grass	Southern end, shaded stream border between large tobacco shed & pasture	June 20, 2001
Holcus lanatus L. Poaceae Common velvet-grass	Exposed subsoil on sides of ditches	May 31, 2001
Leersia oryzoides L. Poaceae Rice-cutgrass	Muddy area near former beaver pond, Widespread near water	Sept. 2, 2001
Panicum sp. (cf. *capillare* L.) Poaceae Panic grass	Center of gravel drive Gravel in front of storage shed Edge of lawn	Aug 14, 2001 Sept. 2, 2001 Sept. 9, 2001
Panicum sp. (cf. *dichotomiflorum* Michx.) Poaceae Panic grass	Mud near former beaver pond In vehicle track	Sept. 2, 2001 Sept. 9, 2001
Panicum sp. (cf. *dichotomum* L.) Poaceae Panic grass	Moist, exposed subsoil on side of ditch, center of gravel drive	June 15, 2001, June 19, 2001, Aug 14, 2001
Phalaris arundinacea L. Poaceae Reed canary-grass	Former beaver dam Water under red maple Widespread	May 20, 2001, June 15, 2001
Phleum pratense L. Poaceae Timothy	Southern end, between large tobacco shed, stream, & pasture	June 19, 2001
Poa sp. (cf. *compressa* L.) Poaceae Canada bluegrass, wiregrass?	Under pecan tree in lawn of abandoned house at entry to Quarry Bog area	July 22, 2001
Schizachyrium scoparium Michx. Poaceae Little bluestem	Edge of lawn, scattered, exposed soil near ditch and Locust Knob Branch	Sept. 29, 2001

(Table 16 occupies pages 120 through 122, alphabetically by genus)

Genus, species Family Common name	Location description	Collection date
Setaria geniculata Lam. Poaceae Knotroot bristle-grass	Open ground near Locust Knob Branch	July 31, 2001
Setaria glauca L. Poaceae Yellow foxtail-grass	Near and on gravel drive Gravel in front of storage shed	Aug 14, 2001, Sept. 2, 2001

Non-Graminoid Monocots from the Orchard Bog Project Area, 2001

Some of these specimens were collected specifically because they were members of difficult genera requiring expertise beyond the author's ability. James Donaldson of the John C. Warden Herbarium aided the identification of these monocots but he was limited by the immaturity of many specimens. The order is alphabetical by genus. All specimens are from the Orchard Bog area.

Table 17.
Non-graminoid monocot species
(Table 17 occupies pages 123 through 125, alphabetically by genus)

Genus, species Family Common name	Location description	Collection date
Carex sp. (cf. *baileyi* Britton.) Cyperaceae Sedge	Wet exposed soil near N. corner	May 31, 2001
Carex bullata Schk. ex Willd. Cyperaceae Sedge	On old peat near N. corner	May 31, 2001
Carex flexuosa Muhl. ex Willd Cyperaceae Sedge	Southern end, woods between pasture and stream near large tobacco shed	June 19, 2001
Carex gynandra Schwein. Cyperaceae Sedge	Running water, Locust Knob Branch By stream in brush by large tobacco shed, southern end.	May 20, 2001 Aug 18, 2001
Carex intumescens v. *intumescens* Rudge. Cyperaceae Sedge	Clumps in areas of mud flat & seepage	June 15, 2001
Carex lupulina Muhl. ex Schkuhr. Cyperaceae Hop sedge	Scattered, growing well among *Phalaris arundinacea*	Oct. 21, 2001

(Table 17 occupies pages 123 through 125, alphabetically by genus)

Genus, species Family Common name	Location description	Collection date
Carex lurida Wahlenberg Cyperaceae Shallow sedge	Clumps in areas of mud flat & seepage.	May 20, 2001
Carex scoparia Schk Cyperaceae Sedge	Slopes of ditch Upper ditch edge, among *Phalaris arundinacea*	May 20, 2001 June 19, 2001
Carex swanii (Fern) Mackenzie. Cyperaceae Sedge	Southern end, woods between pasture and stream near large tobacco shed	June 19, 2001
Carex vulpinoidea Michx. Cyperaceae Fox sedge	Wet, exposed soil near N. corner	May 31, 2001
Cyperus strigosus L. Cyperaceae False-nutsedge	Atop clay dam Exposed soil near Locust Knob Branch	Aug. 14, 2001 Sept. 7, 2001
Eleocharis ovata (Roth) Roemer & Schultes Cyperaceae Blunt spike-rush	Exposed mud, former beaver pond	May 31, 2001
Juncus acuminatus Michx Juncaceae Rush	Subsoil in ditch, Ditch by water Median, marshy end of gravel drive Subsoil at edge of ditch	June 15, 2001 June 26, 2001 Aug. 14, 2001 Sept. 2, 2001
Juncus effusus L. v. *solutus* Frenald & Wiegand Juncaceae Soft rush	Subsoil at edge of ditch, widespread	June 15, 2001
Juncus marginatus Rostk. Juncaceae Rush	Subsoil at edge of ditch	Sept. 2, 2001
Juncus subcaudatus (Engelm.) v. *subcaudatus* Coville & Blake Juncaceae Rush	Subsoil at edge of ditch	Sept. 2, 2001

(Table 17 occupies pages 123 through 125, alphabetically by genus)

Genus, species Family Common name	Location description	Collection date
Juncus tenuis Willd. Juncaceae Rush	Subsoil in and at edge of ditch, widespread	June 15, 2001
Rhyncospora capitellata Michx. Cyperaceae Beak-rush	Sparse, relatively dry ground, exposed subsoil	July 26, 2001
Scirpus polyphyllus Vahl Cyperaceae Leafy bulrush	NE edge of artificial pond at end of gravel track	Aug 3, 2001
Sparganium sp. (cf. *androcladum* [Engelm.] Morong.) Sparganiaceae Bur-reed	Locust Knob Branch, and ponds	June 15, 2001
Additional species; not archived: *Platanthera lacera* Orchidaceae Ragged fringed orchid	Ditch banks, areas of low growth	Not collected

Transect Species Identification, 2001-2002

James Donaldson of the John C. Warden Herbarium aided the identification of many monocots but he was hampered by the immaturity of many specimens. The order is by transect, then alphabetical by genus. Entries accompanied by a question mark are assumptions. Many unidentified seedlings are excluded.

Table 18.
Species identified in transect areas

(Table 18 occupies pages 126 through 131, in order of sampling site)

Transect	Latin name	Common name
1	*Achillea millefolium*	Yarrow
1	*Ambrosia artemisiifolia*	Common ragweed
1	*Calystegia sepium* (?)	Hedge bindweed
1	*Carex lurida*	Shallow sedge
1	*Carex scoparia*	Sedge
1	*Carex tribuloides* (?)	Sedge
1	*Carex vulpiniodiea*	Fox sedge
1	*Cyperus strigosus*	False-nutsedge
1	*Dichanthelium commutatum*	Variable witch-grass
1	*Galium tinctorium*	Bedstraw
1	*Hypericum ellipticum*	St. John's-wort
1	*Juncus effusus*	Soft rush
1	*Linum virginianum*	Flax
1	*Lycopus uniflorus*	Northern bugleweed
1	*Phalaris arundinacea*	Reed canary grass

(Table 18 occupies pages 126 through 131, in order of sampling site)

Transect	Latin name	Common name
1	*Rosa palustris*	Marsh rose
1	*Rubus hispidus*	Swamp dewberry
1	*Scirpus cyperinus*	Woolgrass, bulrush
1	*Sisyrinchium angustifolium*	Blue-eyed-grass
1	*Solidago* sp.	Goldenrod
1	*Sphagnum* sp.	Sphagnum moss
1	*Symphyotrichum puniceum*	Swamp aster, purple-stemmed aster
1	*Vernonia noveboracensis*	Ironweed
1	Not identified to genus or species:	“Brown mosses”
2	*Acer rubrum*	Red maple
2	*Calystegia sepium* (?)	Hedge bindweed
2	*Carex lurida*	Shallow sedge
2	*Carex scoparia*	Sedge
2	*Carex tribuloides*	Sedge
2	*Carex vulpiniodiea*	Fox sedge
2	*Clematis virginiana*	Clematis
2	*Dichanthelium clandestinum*	Deer-tongue witch-grass
2	*Dichanthelium commutatum*	Variable witch-grass
2	*Galium tinctorium*	Bedstraw
2	*Hypericum mutilum*	St. John’s-wort
2	*Hypericum punctatum* (?)	St. John’s-wort
2	*Houstonia serpyllifolia*	Bluet
2	*Juncus acuminatus*	Rush
2	*Juncus effusus*	Soft rush

(Table 18 occupies pages 126 through 131, in order of sampling site)

Transect	Latin name	Common name
2	*Phalaris arundinacea*	Reed canary grass
2	*Potentilla canadensis*	Cinquefoil
2	*Rosa palustris*	Marsh rose
2	*Rubus hispidus*	Swamp dewberry
2	*Rubus* sp.	Blackberry
2	*Sambucus canadensis*	Common elder
2	*Schizachyrium scoparium*(?)	Little bluestem
2	*Scirpus cyperinus*	Woolgrass, bulrush
2	*Scutellaria lateriflora* (?)	Mad-dog skullcap
2	*Sisyrinchium angustifolium*	Blue-eyed-grass
2	*Solidago* sp.	Goldenrod
2	*Sphagnum* sp.	Sphagnum moss
2	*Spiraea alba*	White spiraea
2	*Vernonia noveboracensis*	Ironweed
2	*Viola* sp.	Violet
2	Not identified to genus or species:	“Brown mosses”
3	*Achillea millefolium*	Yarrow
3	*Ambrosia artemisiifolia*	Common ragweed
3	*Calystegia sepium* (?)	Hedge bindweed
3	*Carex lurida*	Shallow sedge
3	*Carex scoparia*	Sedge
3	*Carex tribuloides*	Sedge
3	*Carex vulpiniodiea*	Fox sedge
3	*Carex* sp.	Sedge (large sp.)

(Table 18 occupies pages 126 through 131, in order of sampling site)

Transect	Latin name	Common name
3	*Dichanthelium clandestinum*	Deer-tongue witch-grass
3	*Dichanthelium commutatum*	Variable witch-grass
3	*Eupatorium fistulosum*	Joe-Pye weed
3	*Eupatorium perfoliatum*	Boneset
3	*Galium tinctorium*	Bedstraw
3	*Helinum autumnale*	Sneezeweed
3	*Holcus lanatus*	Common velvet-grass
3	*Houstonia serpyllifolia*	Bluet
3	*Juncus acuminatus*	Rush
3	*Juncus effusus*	Soft rush
3	*Lycopus uniflorus*	Northern bugleweed
3	*Lysimachia cilliata*	Fringed loosetrife
3	*Phalaris arundinacea*	Reed canary grass
3	*Potentilla canadensis*	Cinquefoil
3	*Pycnanthemum muticum*	Mountain mint
3	*Rubus hispidus*	Swamp dewberry
3	*Rubus* sp.	Blackberry
3	*Sambucus canadensis*	Common elder
3	*Schizachyrium scoparium*	Little bluestem
3	*Scirpus cyperinus*	Woolgrass, bulrush
3	*Scutellaria lateriflora*	Mad-dog skullcap
3	*Sisyrinchium angustifolium*	Blue-eyed-grass
3	*Solidago* sp.	Goldenrod
3	*Spiraea alba*	White spiraea

(Table 18 occupies pages 126 through 131, in order of sampling site)

Transect	Latin name	Common name
3	*Symphyotrichum puniceum*	Swamp aster, purple-stemmed aster
3	*Trifolium* sp.	Clover
3	Not identified to genus or species:	"Brown mosses"
4	*Achillea millefolium*	Yarrow
4	*Anthoxanthum odoratum*	Sweet vernal grass
4	*Carex flexuosa*	Sedge
4	*Carex scoparia*	Sedge
4	*Dichanthelium clandestinum*	Deer-tongue witch-grass
4	*Dichanthelium commutatum*	Variable witch-grass
4	*Juncus effusus*	Soft rush
4	*Linum virginianum* (?)	Flax
4	*Lycopus uniflorus*	Northern bugleweed
4	*Monarda fistulosa*	Wild-bergamont
4	*Phalaris arundinacea*	Reed canary grass
4	*Potentilla canadensis*	Cinquefoil
4	*Polygonum* sp.	Smartweed
4	*Pycnanthemum muticum*	Mountain mint
4	*Rhyncospora capitellata*	Beak-rush
4	*Rosa palustris*	Marsh rose
4	*Rubus hispidus*	Swamp dewberry
4	*Scirpus cyperinus*	Woolgrass, bulrush
4	*Sisyrinchium angustifolium*	Blue-eyed-grass
4	*Sisyrinchium mucronatum*	Blue-eyed-grass
4	*Solidago* sp.	Goldenrod

(Table 18 occupies pages 126 through 131, in order of sampling site)

Transect	Latin name	Common name
4	*Spiraea alba*	White spiraea
Dam top	*Bidens* sp.	Beggar-tick
Dam top	*Dichanthelium clandestinum*	Deer-tongue witch-grass
Dam top	*Eupatorium perfoliatum*	Boneset
Dam top	*Hypericum mutilum*	St. John's-wort
Dam top	*Juncus effusus*	Soft rush
Dam top	*Potentilla canadensis*	Cinquefoil
Dam top	*Rubus hispidus*	Swamp dewberry
Dam top	*Rubus* sp.	Blackberry
Dam top	*Solidago* sp.	Goldenrod

Unplanted species identified on experimental plots, 2001-2002

All planted species are recorded in the body of the thesis (Tables 2 and 3), and are not listed here. All persisted into 2002 as at least scattered relics. Entries with a question mark are assumptions. Some specimens could not be identified to the species level because they lacked reproductive structures. Seedlings that could not be identified to the genus level are excluded. The order is alphabetical by genus.

Table 19.
Unplanted species identified in experimental plots

(Table 19 occupies pages 132 through 134, alphabetically by genus)

Latin name	Common name
Ambrosia artemisiifolia	Common ragweed
Amphicarpaea bracteata	Hog-peanut
Aronia melanocarpa	Chokeberry
Bidens sp	Beggar-tick
Calystegia sepium (?)	Hedge bindweed
Carex scoparia	Sedge
Carex tribuloides (?)	Sedge
Carex sp	Sedge (large sp.)
Carex sp	Sedge (small sp.)
Cornus stolonifera	Red-twig dogwood
Cyperus strigosus	False-nutsedge
Dichanthelium clandestinum	Deer-tongue witch-grass
Dichanthelium commutatum	Variable witch-grass
Echinochola crusgalli	Barnyard-grass
Epilobium coloratum	Willow-herb
Erechtites hieraciifolia	Fireweed

(Table 19 occupies pages 132 through 134, alphabetically by genus)

Latin name	Common name
Eupatorium perfoliatum	Boneset
Galium tinctorium	Bedstraw
Galium aparine (?)	Cleavers
Helinum autumnale	Sneezeweed
Hypericum mutilum (?)	St. John's-wort
Hypericum punctatum	St. John's-wort
Leersia oryzoides	Rice-cutgrass
Lepidium campestre (?).	Field cress
Linum striatum	Flax
Lycopus uniflorus	Northern bugleweed
Lysimachia cilliata	Fringed loosetrife
Phalaris arundinacea	Reed canary grass
Phytolacca americana	Poke
Potentilla norvegica	Rough cinquefoil
Polygonum hydropipper	Water-pepper
Polygonum pensylvanicum	Pinkweed
Polygonum punctatum	Smartweed
Polygonum sagittatum	Tear-thumb
Pycnanthemum muticum	Mountain mint
Rosa palustris	Marsh rose
Rubus hispidus	Swamp dewberry
Rubus sp.	Blackberry
Rumex sp.	Dock
Solanum carolinense	Horse-nettle

(Table 19 occupies pages 132 through 134, alphabetically by genus)

Latin name	Common name
Solidago sp.	Goldenrod
Spiraea alba	White spiraea
Spiraea tomentosa	Pink spiraea
Taraxacum officinale	Common dandelion
Verbena urticfolia	White vervain
Vernonia noveboracensis	Ironweed
Not identified to genus or species:	“Brown mosses”

APPENDIX C

ADDITIONAL STATISTICAL TABLES

Table 20.
pH, species richness, and *P. arundinacea* cover

Standard linear regressions.

Predictor	Response	DF	F	P	r	adjusted r^2
pH	*P. arundinacea* cover	1	4.367	0.042	0.30	0.070
pH	Species richness	1	3.467	0.069	-0.27	0.052
P. arundinacea cover	Species richness	1	155.967	< 0.001	-0.88	0.775

Table 21. 2001 simultaneous comparisons.

Bonferroni Simultaneous Comparisons for 2001 plot ANOVA. NS = Not significant, NA = Not applicable. Dependent variable abbreviations: A = aerial, S = subterranean, M = biomass, Ratio = biomass ratio, T = transformed, Cover = Cover Non-Phalaris sp., Richness = Sp. richness.

	Preparations: B = burned, C = control, R = Rodeo herbicide			Planting methods: U = unplanted control, H = herbs, S = seed, W = woody.					
Dependent variable	B vs. C	B vs. R	C vs. R	H vs. U	H vs. S	H vs. W	U vs. S	U vs. W	S vs. W
A M	NS	p<0.001	p<0.001	NS	NS	NS	NS	NS	NS
A M (T)	NS	p<0.001	p<0.001	NS	NS	NS	NS	NS	NS
S M	NS	p<0.001	p<0.05	NS	NS	NS	NS	NS	NS
S M (T)	NS	p<0.001	p<0.05	NS	NS	NS	NS	NS	NS
A/S Ratio	NS	p<0.001	p<0.001	NS	NS	NS	NS	NS	NS
A/S Ratio (T)	NS	p<0.001	p<0.001	NS	NS	NS	NS	NS	NS
Litter	p<0.001	p<0.05	p<0.05	NS	NS	NS	NS	NS	NS
Litter (T)	p<0.001	p<0.001	p<0.01	NS	NS	NS	NS	NS	NS
Cover	NS	p<0.01	p<0.01	p<0.05	NS	NS	NS	NS	NS
Cover (T)	NS	p<0.01	p<0.01	p<0.01	p<0.05	NS	NS	NS	NS
Richness	NS	p<0.001	p<0.001	p<0.01	p<0.001	p<0.05	NS	NS	NS
Planted herbs									
Cover (T)	NS	NS	NS						
Richness	NS	NS	NS						
Monocot vs. dicot herbs									
Cover	p=0.12								
Richness	p=0.11								

Table 22. 2002 simultaneous comparisons

Bonferroni Simultaneous Comparisons for 2002 plot ANOVA. NS = Not significant, NA = Not applicable. Dependent variable abbreviations: A = aerial, S = subterranean, M = biomass, Ratio = biomass ratio, T = transformed, Cover = Cover-Non-Phalaris sp., Richness = Sp. richness.

	Preparations: B = burned, C = control, R = Rodeo herbicide			Planting methods: U = unplanted control, H = herbs, S = seed, W = woody.					
Dependent Variable	B vs. C	B vs. R	C vs. R	H vs. U	H vs. S	H vs. W	U vs. S	U vs. W	S vs. W
A M	NS	p<0.001	p<0.05	NS	NS	NS	NS	NS	NS
A M (T)	NS	p<0.001	p<0.01	NS	NS	NS	NS	NS	NS
S M	NS	p<0.01	p<0.001	NS	NS	NS	NS	NS	NS
S M (T)	NS	p<0.001	p<0.001	NS	NS	NS	NS	NS	NS
A/S Ratio	p<0.05	NS	NS	NS	NS	NS	NS	NS	NS
A/S Ratio (T)	NS	NS	NS	NS	NS	NS	NS	NS	NS
Litter	p<0.01	NS	p<0.001	NS	NS	NS	NS	NS	NS
Litter (T)	p<0.001	NS	p<0.001	NS	NS	NS	NS	NS	NS
Cover	NS	NS	NS	NS	NS	NS	NS	NS	NS
Cover (T)	NS	NS	NS	NS	NS	NS	NS	NS	NS
Richness	NS	NS	p<0.01	NS	NS	NS	NS	NS	NS
Planted herbs									
Cover (T)	NS	NS	p<0.05						
Richness	NS	NS	NS						
Monocot vs. dicot herbs									
Cover	p=0.06								
Richness	p=0.02								

Table 23. Pooled year simultaneous comparisons

Bonferroni Simultaneous Comparisons for pooled plot ANOVA. NS = Not significant, NA = Not applicable. Dependent variable abbreviations: A = aerial, S = subterranean, M = biomass, Ratio = biomass ratio, T = transformed, Cover = Cover-Non-Phalaris sp., Richness = Sp. richness.

	Preparations: B = burned, C = control, R = Rodeo herbicide			Planting methods: U = unplanted control, H = herbs, S = seed, W = woody.					
Dependent Variable	B vs. C	B vs. R	C vs. R	H vs. U	H vs. S	H vs. W	U vs. S	U vs. W	S vs. W
A M	NS	p<0.001	p<0.001	NS	NS	NS	NS	NS	NS
A M (T)	NS	p<0.001	p<0.001	NS	NS	NS	NS	NS	NS
S M	NS	p<0.001	p<0.001	NS	NS	NS	NS	NS	NS
S M (T)	NS	p<0.001	p<0.001	NS	NS	NS	NS	NS	NS
A/S Ratio	NS	p<0.001	p<0.01	NS	NS	NS	NS	NS	NS
A/S Ratio (T)	NS	p<0.001	p<0.001	NS	NS	NS	NS	NS	NS
Litter	p<0.001	p<0.05	p<0.001	NS	NS	NS	NS	NS	NS
Litter (T)	p<0.001	p<0.01	p<0.001	NS	NS	NS	NS	NS	NS
Cover	NS	p<0.01	p<0.001	p<0.01	p<0.05	NS	NS	NS	NS
Cover (T)	NS	p<0.001	p<0.001	p<0.001	p<0.01	NS	NS	p<0.05	NS
Richness	NS	p<0.001	p<0.001	NA	NA	NA	NA	NA	NA

Comparison between years (2001 vs. 2002) for planted herb data

Dependent Variable	
Monocot cover (T)	p=0.01
Monocot richness	p=0.45
Dicot cover (T)	p=0.10
Dicot richness	p=1.00

Table 24
Paired tests for factor changes between years

Tests significant at $p \leq 0.05$. Normally distributed data sets were subjected to paired t-tests.
The Wilcoxon signed rank test (confidence level ≥ 94.5) was used for nonparametric data.
Mathematical transformation to a normal distribution was not useful for any data used to make this table.

Factor	Data type	N	Test type	Test statistic	P
Preparation					
Herbicide	Aerial biomass	12	Paired t	T-value = 3.39	0.006
Herbicide	Shoot/root ratio	12	Paired t	T-value = 3.67	0.004
Herbicide	Litter mass	12	Paired t	T-value = -2.21	0.049
Herbicide	*P. arundinacea* cover	12	Wilcoxon	Wilcoxon = 0.0	0.004
Herbicide	Cover of other sp.	12	Wilcoxon	Wilcoxon = 53.5	0.009
Herbicide	Litter cover	12	Wilcoxon	Wilcoxon = 66.0	0.004
Burned	Litter mass	12	Paired t	T-value = -2.88	0.015
Control	Subterranean biomass	12	Paired t	T-value = 3.49	0.005
Control	Shoot/root ratio	12	Paired t	T-value = -3.25	0.008
Control	*P. arundinacea* cover	12	Wilcoxon	Wilcoxon = 2.0	0.030
Control	Cover of other sp.	12	Wilcoxon	Wilcoxon = 34.0	0.030
Planting					
Woody	*P. arundinacea* cover	9	Wilcoxon	Wilcoxon = 0.0	0.014
Woody	Cover of other sp.	9	Wilcoxon	Wilcoxon = 44.0	0.014
Herbs	*P. arundinacea* cover	9	Wilcoxon	Wilcoxon = 0.0	0.009
Herbs	Cover of other sp.	9	Wilcoxon	Wilcoxon = 36.0	0.014
Herbs	Species richness	9	Paired T	T-Value = -3.30	0.011

Table 25.
P. arundinacea masses and mass ratio, basic statistics

Mass is averaged. Shoot/root ratios are averages from raw data, not from the averages shown here.
"Pre" abbreviates "preparation". Rodeo is a brand of herbicide.
"Woody" planting used two shrubs and an understory fern species.

			Aerial biomass, g/m^2		Subterranean biomass, g/m^2		Shoot/root ratio		Litter, g/m^2	
Pre	Planted	N	2001	2002	2001	2002	2001	2002	2001	2002
Fire	Herbs	9	719	614	2970	2580	0.253	0.269	190	211
Fire	Woody	9	621	656	3263	2945	0.209	0.244	305	298
Fire	Seed	9	810	700	2808	2597	0.386	0.301	126	323
Fire	Nothing	9	646	834	2461	2860	0.277	0.301	196	314
Rodeo	Herbs	9	288	344	1998	1603	0.140	0.233	494	341
Rodeo	Woody	9	362	512	2027	2141	0.182	0.250	266	285
Rodeo	Seed	9	128	602	1986	2404	0.068	0.251	424	348
Rodeo	Nothing	9	268	507	2336	2317	0.111	0.243	395	301
None	Herbs	9	775	691	2714	2976	0.300	0.239	601	556
None	Woody	9	698	530	2456	2763	0.306	0.217	555	686
None	Seed	9	680	683	2813	3495	0.244	0.204	596	458
None	Nothing	9	645	581	2453	3237	0.273	0.192	592	545

Table 26.
Plot species richness and cover, basic statistics

"Pre" abbreviates "preparation". Rodeo is a brand of herbicide.
Litter cover was not subject to ANOVA because its data contained too many zero values.
"Woody" planting used two shrubs and an understory fern species.
Species richness includes *Phalaris arundinacea*

			P. arundinacea live cover, %		P. arundinacea litter cover, %		Cover of other species, %		Species richness	
Pre	Planted	N	2001	2002	2001	2002	2001	2002	2001	2002
Fire	Herbs	3	92.7	97.0	0.0	0.0	7.3	3.0	9.7	8.3
Fire	Woody	3	94.3	98.7	0.0	0.0	5.7	1.3	4.3	7.0
Fire	Seed	3	98.3	96.7	0.0	0.0	1.7	3.3	3.0	3.0
Fire	Nothing	3	100.0	99.7	0.0	0.0	0.0	0.3	1.7	3.0
Rodeo	Herbs	3	61.7	88.7	4.0	0.0	34.3	11.3	18.3	9.3
Rodeo	Woody	3	84.3	96.7	1.6	0.0	14.0	3.3	12.3	15.0
Rodeo	Seed	3	73.7	98.3	16.0	0.0	10.3	1.7	7.3	7.0
Rodeo	Nothing	3	79.0	99.3	14.7	0.0	6.3	0.7	10.0	5.7
None	Herbs	3	95.7	99.3	0.0	0.0	4.3	0.7	7.0	4.0
None	Woody	3	92.7	98.0	0.0	0.0	7.3	2.0	4.3	4.0
None	Seed	3	98.7	98.7	0.0	0.0	1.3	1.3	2.3	3.0
None	Nothing	3	98.3	98.3	0.0	0.0	1.7	1.7	3.0	2.7

Table 27.
Planted monocots and dicots.

"Pre" abbreviates "preparation". Rodeo is a brand of herbicide.

		Cover of planted monocots, %		Cover of planted Dicots, %		Planted monocot species richness		Planted Dicot species richness	
Pre	N	2001	2002	2001	2002	2001	2002	2001	2002
Fire	3	1.0	0.3	1.3	0.7	2.0	1.7	1.3	2.0
Rodeo	3	8.7	3.3	1.7	0.0	3.3	4.0	0.7	1.3
None	3	0.7	0.0	1.0	0.0	1.0	1.7	1.7	0.3

Table 28.
P. lanceolata and *C. glabra* biomass comparison

Two-sample t-test p = 0.202. Two-sample t-test using square-root transformed data p = 0.139.
Mann-Whitney test (95.4 CI) p = 0.260

Species	N	DF	Mean	SEM	Median
Pedicularis lanceolata	12	11	2.33	1.5	0.385
Chelone glabra	12	11	0.279	0.085	0.195

Table 29.
Sensitivity of soil property regression to form of N data

Ordinal logistic regressions. Macronutrient (N & P) significance was sensitive to the form of N data, binary vs. continuous (abbreviated Contin.).

Predictor	Regression Coef.		SE Coef.		Z		P	
	Binary	Contin.	Binary	Contin.	Binary	Contin.	Binary	Contin.
pH	-5.654	-6.165	1.769	1.847	-3.20	-3.34	0.001	0.001
Water	1.062	1.220	1.569	1.599	0.63	0.76	0.499	0.445
Clay	2.48	-40.45	71.15	75.41	0.03	-0.54	0.972	0.592
Sand	-16.49	-59.52	70.80	75.44	-0.23	-0.79	0.816	0.430
Silt	-35.76	-80.44	70.98	76.11	-0.50	-1.06	0.614	0.291
Organic	-34.42	-77.99	72.06	76.85	-0.48	-1.01	0.633	0.310
Phosphorus	-1.327	-2.263	1.215	1.113	-1.09	-2.03	0.275	0.042
Nitrate N	-1.751	-0.0456	1.426	0.02155	-1.23	-2.12	0.220	0.034
Soil structure	-1.915	-2.0536	0.7182	0.7392	-2.67	-2.78	0.008	0.005

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