Resource Recovery Plan for Glade spurge

Euphorbia purpurea (Raf.) Fernald

in Pennsylvania

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Cover photo: *Euphorbia purpurea* photographed at Bryansville Station, York County, Pennsylvania May 16, 2012.

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Table of Contents

List of Figures

List of Tables

Euphorbia purpurea (Raf.) Fernald

Classification

Euphorbia purpurea in the family Euphorbiaceae (Spurge Family) was first named (as *Euphorbia nemoralis*) and described by William Darlington in 1837 in the second edition of *Flora Cestrica* (Darlington 1837).

> "*stem 2—3 feet high..smooth.. leaves 3 or 4 inches long, and about an inch wide, ..heads of florets in a terminal umbel..petaloid segments of the involucre purplish-brown within.. Habitat: moist woodlands: not very common."*

Constantine Rafinesque described the same plant as *Agaloma purpurea* Raf. in Autikon Botanicon (Rafinesque 1840); Rafinesque had previously described the genus *Agaloma*, a segregate of *Euphorbia*, in *Flora Telluriana* (Rafinesque 1836). His description of the species we now call *Euphorbia purpurea* is very similar to Darlington's:

> "*very remarkable species of this genus.. 3 feet high, leaves 4 inches long one broad, flowers not white as in most species but purple rather small: Glades of Pennsylvania Alleg. Mts., very rare."*

Asa Gray renamed this species *Euphorbia darlingtonii* A. Gray (Gray 1848) apparently because the name *E. nemoralis* had previously been applied to another plant by Salisbury (1796). Fernald subsequently combined *Agaloma* with *Euphorbia* which is why we know the plant today as *Euphorbia purpurea* (Raf.) Fern. (Fernald 1932).

A type specimen designated in 1980 by Michael J. Huft is in the collection of the Missouri Botanical Garden (MO-2196699). Although collected by Darlington in West Chester, Pennsylvania, it is not dated and has limited location data (Figure 2).

In 2011 a specimen at the Academy of Natural Sciences of Philadelphia (PH-01070036) was designated a neotype (Geltman et al. 2011). This sheet, also collected by Darlington, carries full location information and the date of collection, July 18, 1819 (Figure 3).

Synonyms

Euphorbia nemoralis Darlington (1837)
Agaloma purpurea Raf. (1840)
Euphorbia darlingtonii A.Gray (1848)
Tithymalus darlingtonii (A.Gray) Small (1903)
Euphorbia purpurea (Raf.) Fern. (1932)
Galarhoeus darlingtonii (A.Gray) Small (1933)

Figure 1. Type specimen, collected by Wm. Darlington in West Chester, Pennsylvania, now in the Herbarium of the Missouri Botanical Garden (MO-2196699). Curiously, this specimen is not dated. It was originally identified as *E. nemoralis*, by Darlington, annotated as *E. darlingtonii* in 1850, and annotated again as *E. purpurea* (Raf.) Fernald by Michael J. Huft in 1980.

Figure 2. A neotype, designated by Geltman et al. (2011), is in the collection of the Herbarium of the Academy of Natural Sciences of Philadelphia (PH-01070036). Unlike the type specimen shown in Figure 2, this sheet has label information which reads "shaded rivulet on the barrens above S. Stringfellow's, West Chester, Pennsylvania, July 11, 1819, Wm. Darlington. Identified by Darlington as *E. nemoralis*, it was later annotated as *E. darlingtonii* A. Gray. Geltman et al. (2011) also designated this specimen as the lectotype for *E. darlingtonii* A. Gray.

Description

Morphology

Euphorbia purpurea is an herbaceous perennial with a cluster of one to many stems up to 1.3 m tall and 1 cm in diameter arising from a short, stout rhizome. All parts of the plant contain an acrid milky sap. With the exception of the first pair of photosynthetic leaves produced in the seedling stage, stem leaves are alternate, elliptic to narrowly lance-oblong, with an entire margin, and sparse hairs beneath. Branching occurs only in conjunction with the inflorescence, which develops at the stem apex.

The inflorescence consists of a primary umbel with 5—8 ascending rays at the stem apex, smaller secondary umbels are borne on branches from the upper leaf axils. As in all members of the genus *Euphorbia*, the flowers of *E. purpurea* are highly reduced and enclosed in a cup-like involucre, termed a cyathium, which mimics a single flower in appearance. The cyathium contains highly reduced male flowers, each consisting of a single stamen, surrounding a single female flower which is elevated on a stalk. Five nectar-secreting glands are present on the margin of the cyathium.

The fruit is a 3-lobed, warty capsule 6—8 mm in diameter containing a single seed in each of the three (rarely four), locules. Seeds are 3—4 mm in diameter, subglobose, and carunculate.

Figure 3. Reproductive structures, clockwise from upper left: inflorescence; cyathium with staminate flowers; cyathium with pistillate flower; cyathium with developing fruit.

Phenology

In Pennsylvania *E. purpurea* plants typically begin growth in early April and achieve 85—100 percent of their final height by mid-June. Flowering occurs in May and early June. Fruits are mature and dispersing seeds from late June into the first week of July (Loeffler and Wegner 2000). At low elevations in Virginia, flowering may occur as early as mid-April with mature fruit present in June (Terwilliger 1991). Senescence, which typically begins in July, is affected by soil moisture; occurring earlier in dry years.

Reproduction

Euphorbia purpurea is an example of a K-selected species (McArthur and Wilson 1967). Individual plants are long-lived, how long is not known, but of 844 mature plants marked at a site in Perry County, PA in 1995, 263 were still present in 2012. However, investment in reproduction is low. During the 18 years during which data was collected at the site the proportion of plants flowering each year varied from 1.7 percent to 7.6 percent. The typical number of seeds possible from a single inflorescence (cyathium) is three, rarely four, but not all pistillate flowers produce seeds.

Pollination

Inflorescences are protandrous (staminate flowers mature first). Most species in the Euphorbiaceae are insect pollinated (flies, bees. wasps, butterflies); nectar, produced by glands on the rim of the cyathium, is the floral attractant (Judd et al. 2008). Specific pollinators of *E. purpurea* are not known.

Seed Dispersal

Seeds of *E. purpurea* are ovoid to subglobose and 3—4 mm long (Fernald 1950). They are dispersed ballistically. When a capsule reaches the right stage of maturation, it explodes, ejecting the seeds. Seedlings have been found 0.1 – 5.8 m from the parent plant *in situ* (Loeffler and Wegner 2000). *Euphorbia purpurea* seeds also have a caruncle which may serve to attract ants (Fernald 1950). Longer distance movement may occur through water transport, as some sites are on floodplains; or, alternatively, seeds may be transported in mud stuck to an animal's exterior (epizoochory). There are no data to document the actual occurrence of mechanisms other than mechanical ejection from the capsule.

Seed Germination and Soil-banking Potential

Carol Loeffler has found that seeds of *E. purpurea* collected in late June to early July do best if they are half-buried in moist soil and held at room temperature for five months followed by refrigeration for five months. Almost all seeds germinated within a few days when subsequently exposed to 20˚C and light. The germination rate was much lower after only three months of chilling; however, a second cold treatment resulted in growth. Dry storage followed by chilling was not effective (C. Loeffler, personal communication, March 30, 2012).

The pattern of seedling appearance observed in the field indicates that most seeds germinate in the summer following the year that they were produced. But occasionally a seedling appears in a spot where seeds had last been produced two years previously (Loeffler and Wegner 2000). The behavior of seeds in refrigeration trials and patterns of seedling appearance in local populations suggest that viable seeds do not persist in the soil for longer than two years (C. Loeffler, personal communication, March 30, 2012). It is possible that seeds that became buried might remain dormant until again exposed to light, however there are no relevant data.

Seedling survival is low and new plants are slow to reach reproductive size in situ. Data from Perry County reveal that of 728 seedlings recorded between 1995 and 2012, only 16 were still alive in 2012. The only seedling-origin plant to flower did so at 13 years of age (C. Loeffler,

unpublished data). In contrast, several potted plants raised from wild-collected seed flowered as two-years olds (Loeffler and Wegner 2000).

Asexual Reproduction

It has been suggested that long-lived *E. purpurea* clumps, which are multi-stemmed, may fragment over time as their short rhizomes lose connectivity. This could make it difficult to determine what constitutes a genet (Terwilliger 1991; Loeffler and Wegner 2000).

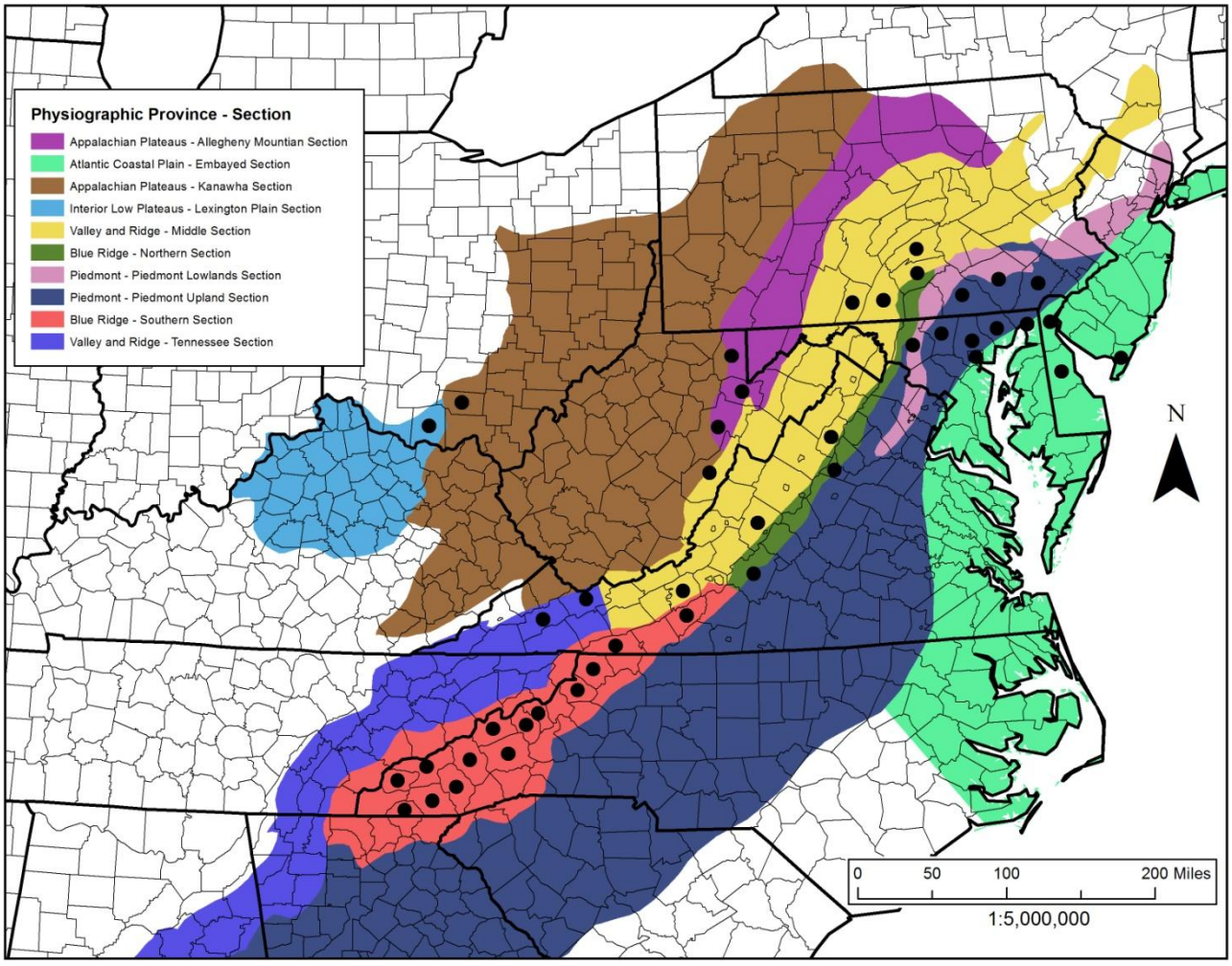
Ecology

Range

The global range of *Euphorbia purpurea* extends from New Jersey and Pennsylvania west to Ohio and south to Delaware, Maryland, Virginia, West Virginia and western North Carolina (NatureServe 2011).

Most populations are in the Valley and Ridge, Piedmont Upland, Blue Ridge, and Allegheny Mountains Section of the Appalachian Plateau Physiographic Provinces in a swath that extends from southern Pennsylvania through eastern Maryland, West Virginia, Virginia, and western North Carolina. In addition, there are a few outliers in Delaware and New Jersey that are in the Atlantic Coastal Plain (Figure 4).

Figure 4. Global Distribution of *Euphorbia purpurea* by County and Physiographic Province
Sources: United States Geologic Survey (2012a) and state heritage programs



The current range of *E. purpurea* suggests that the southern Appalachians may have provided glacial refugia for this species. Gonzales et al. (2008), working with haplotypes of *Trillium cuneatum* and McLachlan et al. (2005) using *Acer rubrum* and *Fagus grandifolia* have provided support for the existence of multiple refugia in the southern Appalachians during the last glacial maximum. *Trillium cuneatum*, like *E. purpurea*, lacks effective long-distance seed dispersal mechanisms. Its present-day range extends from Louisiana to North Carolina and Kentucky (Flora of North America 2002). *Acer rubrum* and *Fagus grandifolia* are major components of the forest canopy in *Euphorbia purpurea* habitat today.

Habitat

Euphorbia purpurea is found growing in a variety of conditions from saturated wetland soils to occasionally, well-drained upland slopes, and from deep shade to full sun. Geological substrates include limestone (PA, VA), schist (PA), dolomite (OH, VA), serpentinite (PA), mafic rock (NC), and pyroxene granulite gneiss (VA).

Habitat is described as rich woods, swampy woods or thicket, forested seep, seepage swamp, cow pasture, floodplain forest, floodplain talus slope, rocky forested slopes, rocky colluvial banks, ecotone between wet meadow and woods, shrubby edge of calcareous fen/seep, old field, and high elevation seepage swamp. A common factor is the presence of dependable high moisture levels early in the season.

At one site in West Virginia *E. purpurea* is part of a ***Balsam fir – Black ash Swamp*** natural community which is ranked as critically imperiled at the global (G1) and state (S1) levels (Byers et al. 2007).

Figure 5. Hillside seep at Bryansville Station, York County, Pennsylvania. Location of *Euphorbia purpurea* is indicated by the box. Dominant species include *Osmunda cinnamomea, Symplocarpus foetidus,* and *Impatiens capensis. Photographed 5/16/2012.*

Successional Status

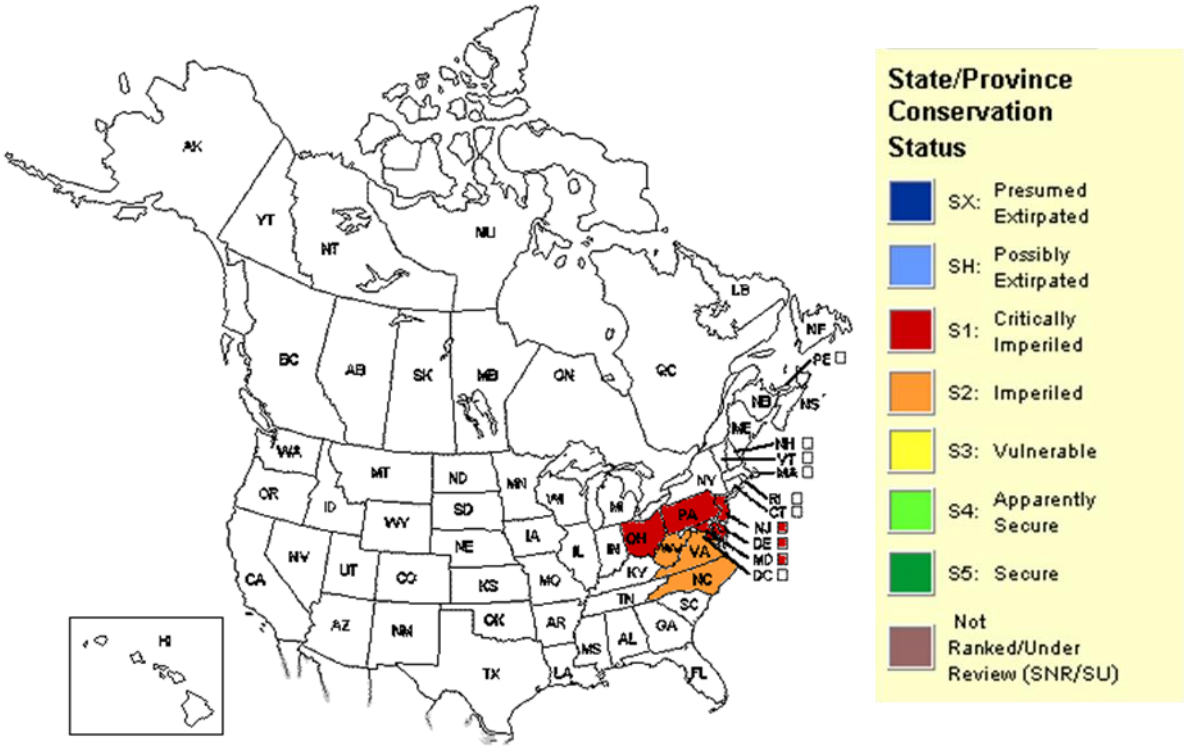
Euphorbia purpurea is recorded as growing in deep shade, filtered light, partial shade, and full sunlight; however, plants with more sunlight typically have more stems, are shorter in stature, and have a greater proportion of flowering stems (VA Natural Heritage Program 2012). At several sites in Pennsylvania, deliberate thinning of tree and/or shrub cover has apparently resulted in increasing the proportion of flowering stems (C. Loeffler, personal communication).

Conservation Status

In 1985 *Euphorbia purpurea* was listed under the Federal Endangered Species Act, category 2, proposed. Category 2 denotes species for which listing as endangered or threatened may be appropriate, but further biological research is needed to determine the correct status (Federal Register 1985).

Euphorbia purpurea has a global rank of vulnerable (G3); it is ranked critically imperiled (S1) or imperiled (S2) in every state in which it has been found (Figure 6) (NatureServe 2011).

Figure 6. Range and conservation status of *Euphorbia purpurea* Fernald
Source: NatureServe 2011.



Euphorbia purpurea in Pennsylvania

History of the Discovery of *Euphorbia purpurea*

William Darlington of West Chester, PA first collected the plant that we now know as *Euphorbia purpurea* (Raf.) Fern. in Chester County, Pennsylvania in1819. He referred to it in a comment included under the genus *Euphorbia* in *Florula Cestrica*:

> "*I have some specimens which I collected in the beginning of July, along a shaded rivulet, on the Barrens N. W. of Stringfellow's; and which, in the opinion of Dr. Torrey, come nearer to the E. sylvatica of Europe, than to any other. It is possible they may have strayed from a garden,—although found in a very retired spot."* (Darlington 1826)

In 1837 Darlington included the species in his treatment of *Euphorbia* in *Flora Cestrica* as *E. nemoralis* Darlington with the following comment:

> "*This plant has been found in several places in the mica-slate range in retired shady vallies, —and also in London Grove—in situations, and under circumstances, which seem to forbid the idea of its having been introduced. I have never yet seen any specimen of it from abroad, nor have I met with any botanist who was acquainted with the plant. Mr. Nuttall is decidedly of the opinion that it is a non-descript; and as I am disposed to concur with him, I submit it, for the present, with the foregoing specific name." (Darlington 1837)*

In the 1853 edition of *Flora Cestric*a Darlington listed the plant as *E. darlingtonii* A. Gray with the following observation:

> *"This species has long been found, growing very luxuriantly in thickets, along some of the rivulets among our slaty hills,—and in Londongrove. The Rev. M.A. Curtis also met with it on the mountains of North Carolina; and Mr. John M'Minn informs me that he finds it in abundance along Spring Creek, near Bellefont, in Centre County, Penna. It is rather remarkable, that a plant of its size should have been so long overlooked, by the Botanists."* (Darlington 1853).

Early Records

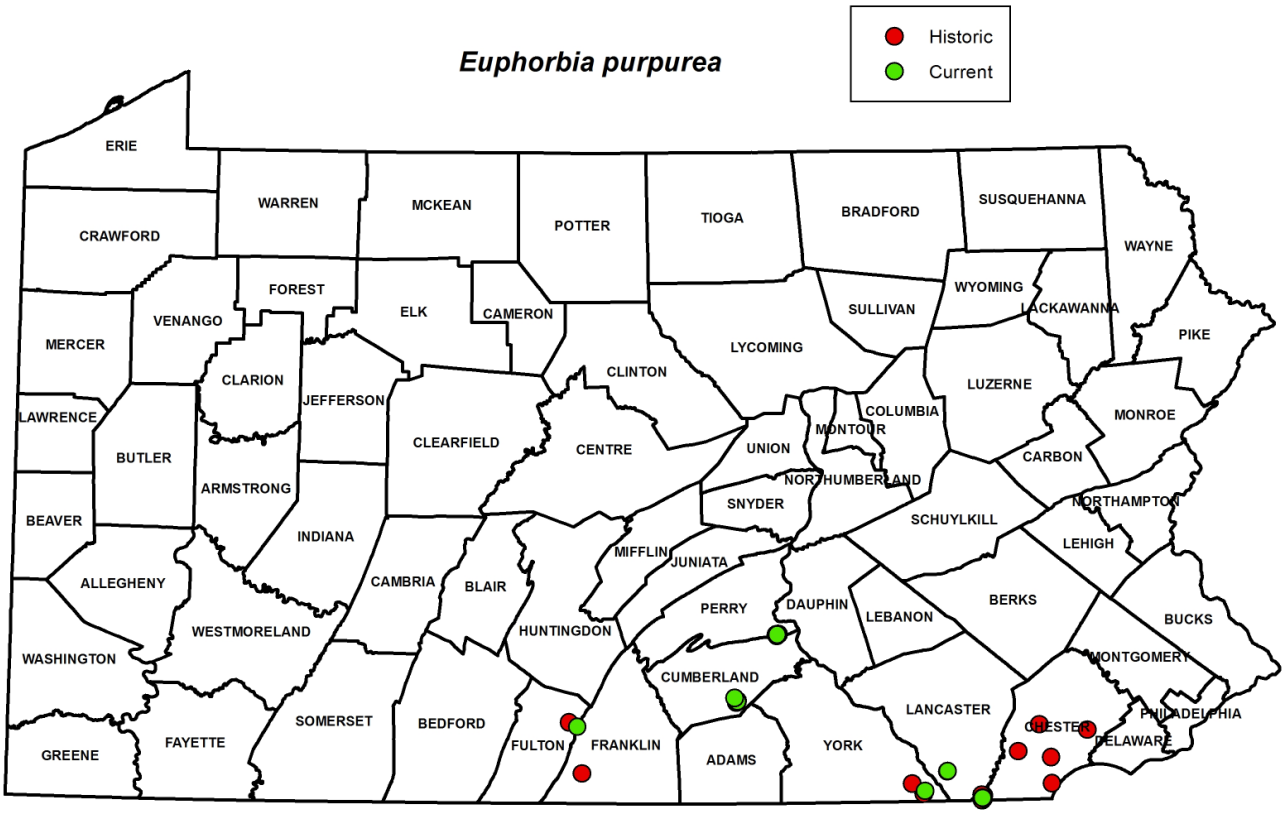
The earliest existing specimens of *Euphorbia purpurea* were collected by William Darlington in Chester County, Pennsylvania in 1819 (Figures 1 and 2). Other early collections include those from Franklin Co. in 1846, Chester Co. in 1860, and Lancaster Co. in 1884 and 1886. In the early 1900s Cumberland County was added to the known range in the state (Table 1). Although Darlington referred to a population near Bellefont in Centre County, PA (see box above), we have not found a corresponding voucher specimen (Table 1).

Table 1. *Euphorbia purpurea* herbarium records from Pennsylvania

Sources: Herbarium of the Academy of Natural Sciences of Philadelphia (PH); Carnegie Museum Herbarium (CM), Morris Arboretum Herbarium (MOAR), Missouri Botanical Garden Herbarium (MO), Franklin and Marshall College Herbarium (F&M), Tom Smith private collection (TSMIT).

Year	*Collector name*	*County*	*Location*	*Ancillary location*	*Herbarium*
no date	Darlington, Wm.	Chester	West Chester		MO
1819	Darlington, Wm.	Chester	West Chester	Barrens above S. Stringfellow's, shaded rivulet	PH
1829	Darlington, Wm.	Chester	West Chester		PH
1846	Porter, T.C.	Franklin	Mercersburg		PH
1860	Canby, W.M.	Chester			CM
1884	Aschman, F.T.	Lancaster			CM
1885	Galen, J.	Lancaster			CM
1893		Chester	Coatesville	J, Hope's meadows	PH
1894	Stone, H.E.	Chester	Coatesville		PH
1921	Gress	Cumberland	Mount Holly		PH
1924	Pennell, F.W. 12223	Chester	Lees Bridge	Serpentine bank	PH
1927	Bright, J.	Cumberland	Hunters Run		CM
1928	Stone, H.E.	Chester	Lees Bridge	near, hillside thicket close to serpentine barren	PH
1928	Stone, H.E.	Chester	Lees Bridge	at Octoraro Cr, moist thicket	PH
1929	Wilkens, H. 160	Chester	Lees Bridge	near, serpentine barrens	PH
1931	Stone, H.E.	Chester	Landenberg	moist wood below	PH
1931	Long, B. 35363	Chester	Landenberg	1 mi S, moist woods along streamlet, trib. of White Clay Cr.	PH
1951	Wherry, E.T.	Chester	Cochranville	1.5 mi ESE, wooded stream bank	PH
1952	Groff, E.	Lancaster	Fishing Creek	rear entrance to Fishing Creek Glen	F&M
1952	Wherry, E.T.	York	Woodbine		PH
1958	Huttleston, D.G. 1551	Chester	London Grove	0.5 mi W, swampy woods N of Rt. 926	PH
1959	Wherry, E.T.	York	Bryansville	0.5 mi ENE	PH
1960	Emory	Fulton	Knobsville		PH
1961	Wherry, E.T.	Fulton	Cowans Gap	(Cowans Gap State Park)	PH
1962	Mehring	Perry	Lambs Gap		PH
1987	Smith, T.L.	Chester	Goat Hill	serpentine barrens	TSMIT
1990	Rhoads, A.F.	Perry	Lambs Gap	0.45 mi N, along Trout Run	MOAR
2011	Rhoads, A.F. & Loeffler, C.	Cumberland	Hunters Run	Exclosure 1	MOAR
2012	Rhoads, A.F. & Block, T.A., Kunsman, J., Seymour, S.	Lancaster	Chestnut Level	2.4 km WNW, along Fishing Creek	MOAR

Figure 7. Map of historic and current Pennsylvania populations of *Euphorbia purpurea*



Status of Current Occurrences

Seven extant populations of *Euphorbia purpurea* are currently known in Pennsylvania; they occur in Chester, Cumberland, Fulton, Lancaster, Perry, and York Counties (Figure 7) (PNHP 2011).

In 1995 a multi-year study of population dynamics at three sites in Cumberland and Perry Counties was initiated (Loeffler and Wegner 2000). In 2000, two additional sites in Chester and Fulton Counties were added for a total of five. The methodology included locating and tagging every plant (genet) in each population, distinguishing individual stems (ramets) and plants (genets), and observing the plants three times each year (mid-June, mid-July, and mid-August).

Evidence of herbivory by deer or insects, signs of disease, senescence, and mortality were all recorded. Measurements included stem diameter; stem height; and flower, fruit, and seed production. Every year seedlings were searched for within a 7.5 m-radius around each plant that had produced fruit during the previous two years. In addition, downstream swamp habitat was also searched in case flooding had redistributed seeds. New seedlings were tagged and followed in succeeding years. Results of the first four years of this survey were published (Loeffler and Wegner 2000); however annual data collection has continued through 2012 and is ongoing (C. Loeffler, personal communication).

Hunters Run, Cumberland County

Euphorbia purpurea was first documented at Hunters Run in 1927 (Table 1). The monitored population of *E. purpurea* at Hunters Run is within the Appalachian Trail Corridor on land currently owned by the National Park Service. The plants occur in three clusters. Additional plants are present on adjacent private lands, but they were not included in the study. This site is underlain by Tomstown Formation dolomite (PA Bureau of Topographic and Geologic Survey 2001).

Enclosure 1, which is 50 x 25 feet, contains the largest number of *E. purpurea* stems (15 plants with a total of 23 stems in July 2011). It lies just off the Appalachian Trail. The habitat of exclosure 1 is seasonally moist, successional forest. In July 2011 it had no evidence of seeps or hummocks and no sign that standing water was present at any time during the year (A. Rhoads, personal observation).

Canopy trees included *Acer rubrum* and *Nyssa sylvatica*; *Carya ovata, Fraxinus americana, Quercus rubra. Amelanchier arborea,* and *Carpinus caroliniana* formed the understory. Shrubs and vines included *Lindera benzoin, Hamamelis virginiana, Sambucus canadensis, Vaccinium corymbosum, Viburnum dentatum, Clematis virginiana, Parthenocissus quinquefolia* and the non-native invasive *Berberis thunbergii.*

The ground layer was dominated by *Rubus hispidus, Osmunda cinnamomea,* and *Viola* sp. Other species included *Carex crinita, C. folliculata, Chelone glabra, Dichanthelium* spp. *Maianthemum canadense, M. racemosum, Podophyllum peltatum, Sanguisorba canadensis, Symplocarpus foetidus, Thalictrum pubescens, and Thelypteris noveboracensis.*.

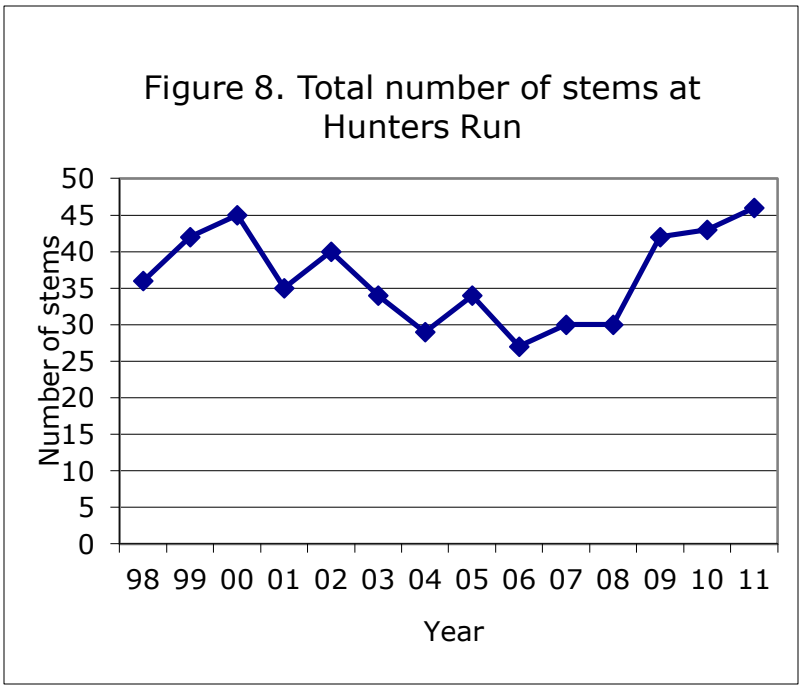
Exclosure 2 contained five *E. purpurea* plants with a total of 12 stems in 2011. This site had a canopy dominated by *Acer rubrum* with *Fraxinus nigra* and *Nyssa sylvatica*. The shrub layer was dominated by *Lindera benzoin*. *Symplocarpus foetidus* was the dominant herbaceous species with *Hackelia virginiana, Impatiens capensis, Maianthemum canadense, Onoclea sensibilis, Osmorhiza claytonii, Persicaria arifolia, Sanicula* sp., and *Thelypteris noveboracensis. Microstegium vimineum was abundant;* other non-native invasive species included *Alliaria petiolata* and *Vincetoxicum nigrum* (A. Rhoads, personal observation).

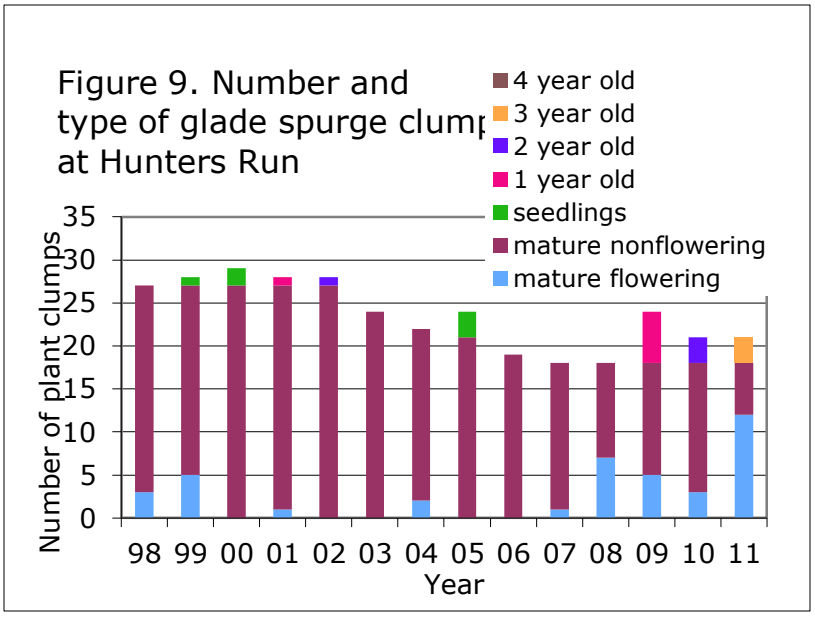
Exclosure 3 is located along a swale and suffered damage to the fence during flooding; the exclosure was subsequently repaired in August 2011. It contained a single *E. purpurea* plant with 10 stems in July 2011. The canopy at this site is dominated by *Acer rubrum* and *Fraxinus* sp. Shrubs include *Hamamelis virginiana* and *Lindera benzoin*. In July 2011 the herbaceous layer was dominated by two non-native invasive species: *Microstegium vimineum* and *Persicaria longiseta*. *Persicaria perfoliata*, another troublesome invasive, was also present. Native herbaceous species included *Boehmeria cylindrica, Impatiens capensis, Symplocarpus foetidus,* and *Thelypteris noveboracensis* (A. Rhoads, personal observation).

Since the summer of 2002 each of the three sub-populations at Hunters Run has been surrounded by a deer exclosure fence. With the exception of brief breaches of the fence in 2006 and 2007, deer damage has ceased. The combination of fencing and removal of some woody vegetation appears to have reversed the decline in number of stems that had occurred from 1995 to 2003

(Figure 8). Reproductive effort has increased with one or more plants flowering every year from 2008 to 2011. The number of seedlings surviving beyond their first year increased in 2010 (Figure 9).

Overall in 2011 the Hunters Run population consisted of 21 plants with 46 stems, of which 13 flowered. Comparable data for 1995 was 30 plants with a total of 44 stems of which one stem flowered. However these results must be considered anecdotal since the treatments were not replicated there were no control plots.





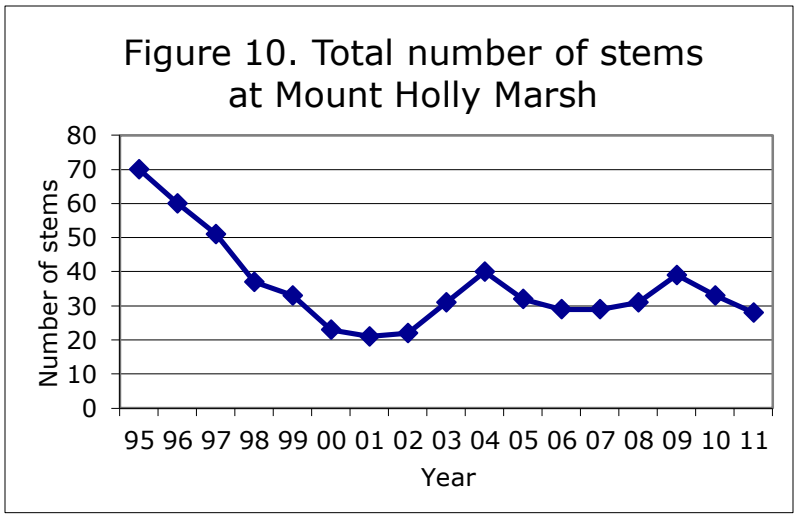
Mount Holly Marsh, Cumberland County

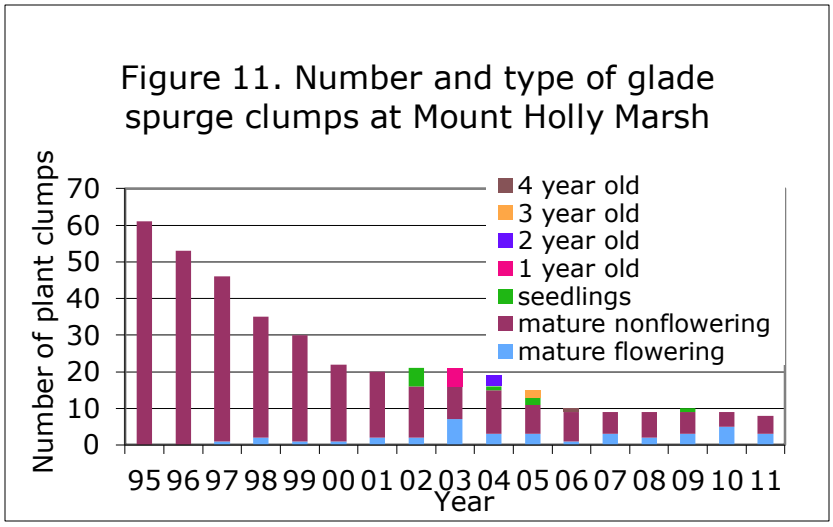
This site is described as a rich, circum-neutral seepage swamp dominated by shrubs and herbaceous plants and exhibiting perennial, strong water flow (PNHP 2011; Western Pennsylvania Conservancy 1998). It is owned by The Nature Conservancy. Mount Holly Marsh has partial tree cover (30 percent) including *Acer rubrum* and *Fraxinus nigra* with occasional *Pinus strobus* and *Tsuga canadensis*. The shrub layer contains *Lindera benzoin, Viburnum recognitum, Ilex verticillata, Vaccinium corymbosum, Hamamelis virginiana, Toxicodendron vernix* and *Rhamnus alnifolia*. The saturated soil also supports a robust herbaceous layer of *Symplocarpus foetidus, Osmunda cinnamomea, O. regalis, Impatiens capensis, Arisaema triphyllum, Maianthemum canadense*, and *Solidago patula*. *Euphorbia purpurea* grows on the tops and sides of hummocks (Loeffler and Wegner 2000).

The earliest record of *E. purpurea* at Mount Holly is an herbarium specimen collected by Gress in 1921 (Table 1). In 1988, when the Pennsylvania Natural Heritage Program began monitoring the Mount Holly population, there were 20 plants including 11—50 stems (PNHP 2011).

The area was partially fenced in 1997 and completely fenced a few years later. However, deer have gotten in several times. The number of plants declined from 1995 to 2000 when it held at approximately 20 for several years. Coincident with deer break-ins, the population declined further to 8—10. In 2011 there were eight plants consisting of 28 stems, four of which flowered (Figure 10, Figure 11).

Although one or more flowering stems have been produced in each of the past five years, and seedlings were noted in 2005 and 2009, there is no evidence of recruitment (Figure 11).





Cowans Gap, Fulton County

Euphorbia purpurea has been known at Cowans Gap since 1961 (Table 1) when it was discovered by Edgar T. Wherry. The plants are growing in mucky hydric soil in sphagnous seepage swamp depressions in the valley of Little Aughwick Creek upstream of the lake at Cowan's Gap State Park.

Associated species include *Osmunda cinnamomea, O. regalis, Lindera benzoin, and Ilex verticillata*; the surrounding forest has a canopy dominated by *Liriodendron tulipifera, Quercus alba, Q. rubra,* and *Acer rubrum,* with an understory of *Nyssa sylvatica* and *Magnolia acuminata*. Construction of a sewer line along the creek valley in 1965 may have impacted the population (PNHP 2011). From 1985 to 1995 population size declined from approximately 70 plants to less than 20 (PNHP 2011).
This site is underlain by shale and limestone of the Bloomsburg and Mifflintown Formations (PA Bureau of Topographic and Geologic Survey 2001; Geyer and Wilshusen 1982). It was clearcut between 1893 and 1907 (DCNR 2012).

Yearly monitoring began in 2000, at which time fencing was installed around all existing plants. However, browsing of plants growing close to the fence was recorded between 2005 and 2010. A steady increase in the number of stems occurred from 2004 to 2009, while plant number, which had been about 10, increased to approximately 15 starting in 2009 as a result of seedling recruitment (Figures 12). The number of plants flowering has increased from 1 or 2 per year to 3—5 (Figure 13). One greenhouse raised plant, transplanted into the plot bloomed at four years of age.

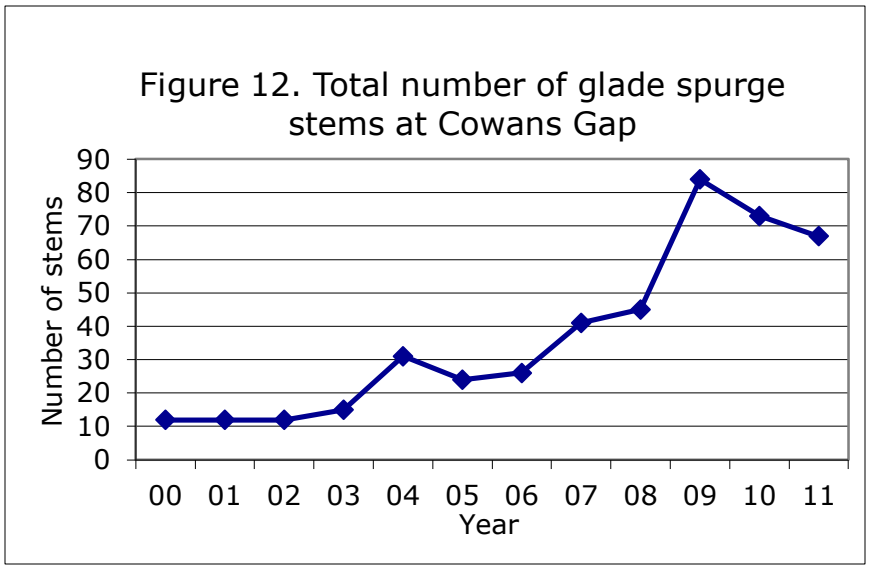


Figure 12. Total number of glade spurge stems at Cowans Gap
Number of stems
90
80
70
60
50
40
30
20
10
0
00 01 02 03 04 05 06 07 08 09 10 11
Year

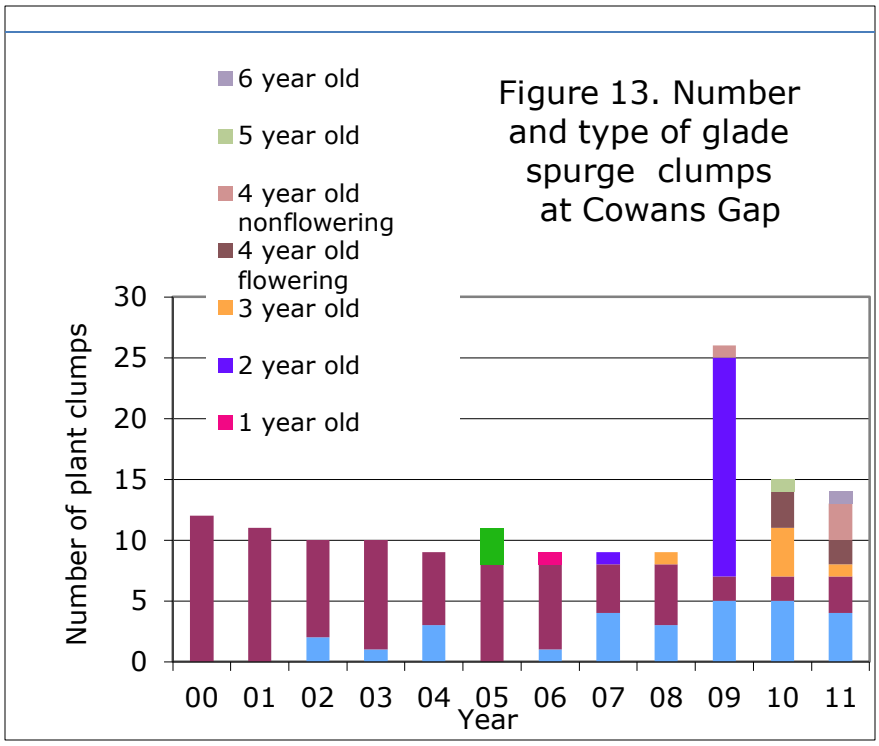


Figure 13. Number and type of glade spurge clumps at Cowans Gap
6 year old
5 year old
4 year old nonflowering
4 year old flowering
3 year old
2 year old
1 year old
Number of plant clumps
30
25
20
15
10
5
0
00 01 02 03 04 05 06 07 08 09 10 11
Year

Goat Hill, Chester County, PA

Euphorbia purpurea was first collected in the vicinity of Goat Hill at Lees Bridge in 1924 by Francis Pennell (Table 1). The extant population at Goat Hill is scattered along a tributary of Octoraro Creek, some in the creek bottom but many on the slope above the creek. They are growing in small openings in what is otherwise a continuous thicket of *Smilax rotundifolia*. Scattered trees include *Acer rubrum, Quercus stellata, Quercus rubra, Quercus coccinea, Sassafras albidum, Juniperus virginiana*, and *Pinus rigida*. The most abundant shrub is *Lindera benzoin*; others include *Quercus prinoides, Corylus americana*, and several non-native, invasive species: *Elaeagnus umbellata, Rosa multiflora*, and *Berberis thunbergii* (A. Rhoads, personal observation, July 2011).

The herbaceous flora is dominated by the non-native, invasive *Microstegium vimineum* throughout; other species include *Adiantum pedatum, Polystichum acrostichoides, Athyrium filix-femina, Ageratina altissima*, and *Eutrochium fistulosum*. At one site on the valley floor *Symplocarpus foetidus, Arisaema trifolium*, and *Osmunda regalis* are present.

This site is underlain by ultramafic rocks including serpentinite (PA Bureau of Topographic and Geologic Survey 2001).

Deer damage ranging from 5 to 30 percent of the stems per year has been observed at this site (Carol Loeffler, personal communication). There is a single deer exclosure at Goat Hill. Located on the valley floor, it contained 17 *Euphorbia purpurea* plants in 2011. *Smilax* and *Microstegium* are being removed by pulling or clipping within the exclosure.

The total number of plants and stems at Goat Hill has declined steadily since data collection began in 2001. Initially the population consisted of 140 plants with a total of 335 stems 10 of which flowered. In 2012 the Goat Hill population consisted of 69 plants with 180 stems, none of which flowered (Figure 14 and 15).

Within the exclosure, the decline in plant number has been slower, but seedlings have not been recorded since 2000 although flowering occurred yearly until 2011. Currently, the population consists entirely of mature, non-flowering individuals (Figure 16).

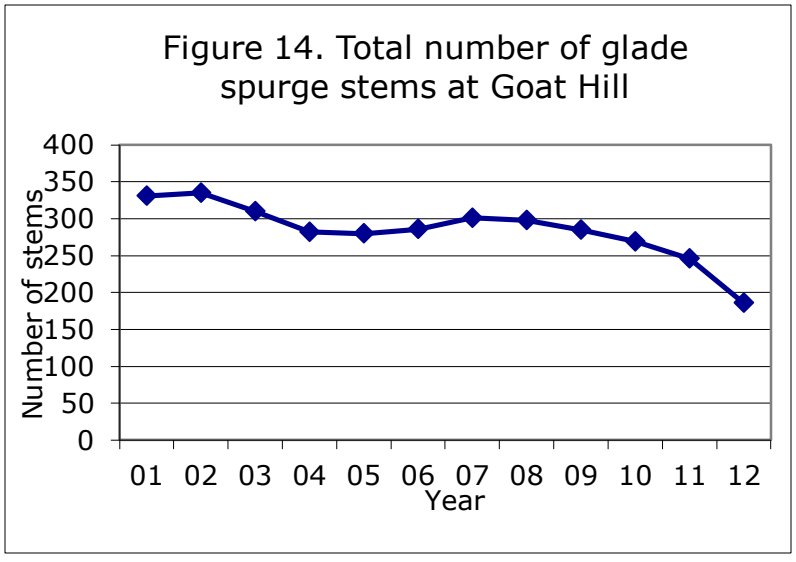


Figure 15. Number and type of glade spurge clumps at Goat Hill

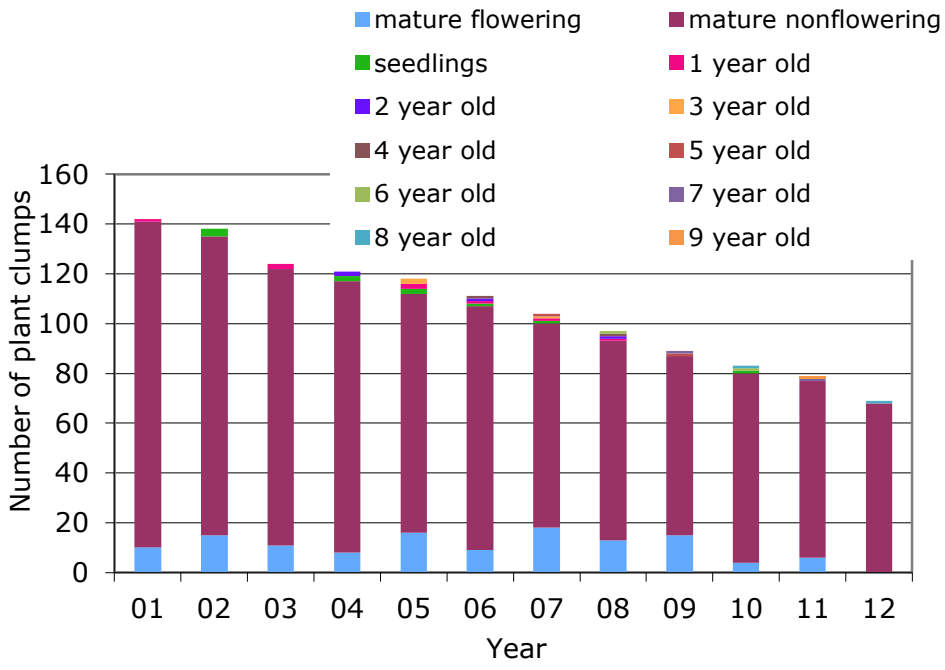
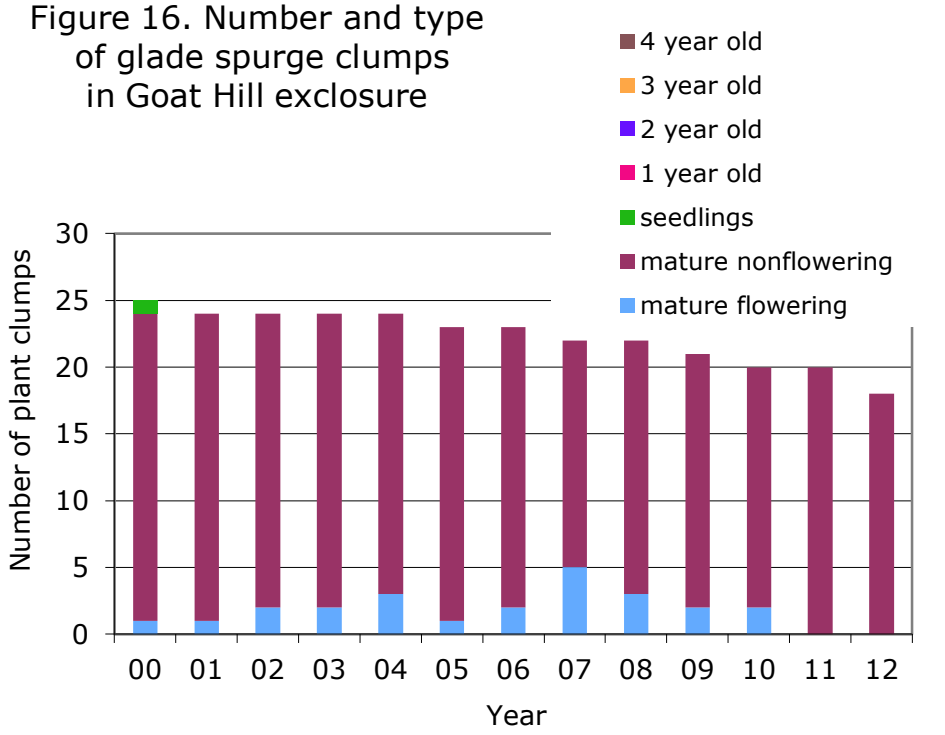


Figure 16. Number and type of glade spurge clumps in Goat Hill exclosure



Marysville (Lambs Gap), Perry County
Marysville is the largest *E. purpurea* population known in Pennsylvania. *Euphorbia purpurea* was first documented at this site in 1962 (Table 1). The Marysville population extends along the narrow valley of Trout Run for 0.8 km west from Lambs Gap Road in State Game Lands Number 170.

Euphorbia purpurea occurs in sub-populations of 1—65 plants located in back channels (oxbows) and seepage wetlands that are fed by springs along the valley walls. The patchy distribution is at least in part because the seepage areas and back channels in which the plants are found are separated by upland habitat.

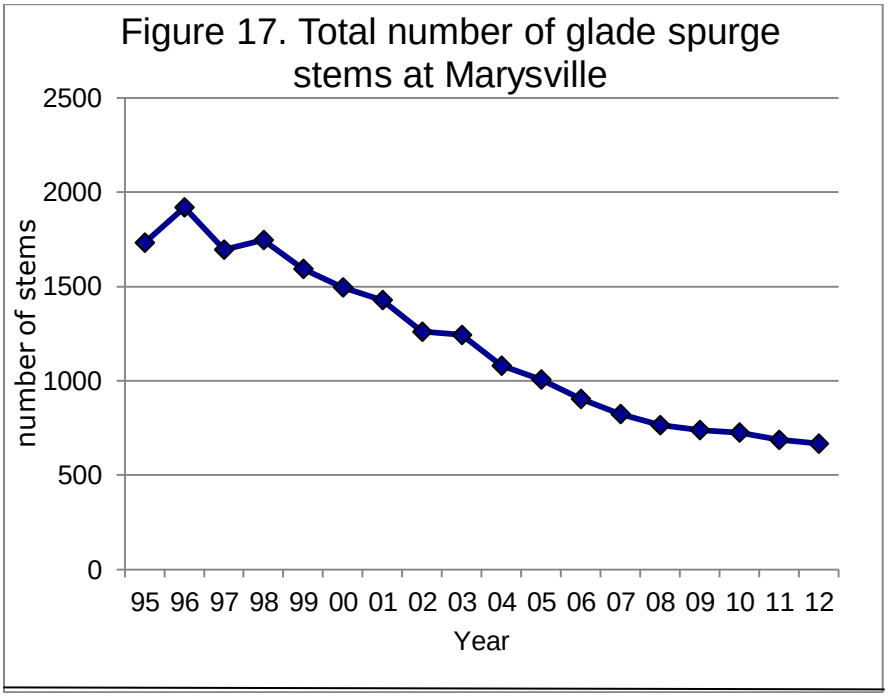
This site is underlain by shale and limestone of the Bloomsburg and Mifflintown Formations, limestone and chert of the Onodaga and Old Port Formations, and fossiliferous siltstones of the Hamilton Group (PA Bureau of Topographic and Geologic Survey 2001; Geyer and Wilshusen 1982). Water flow is classified as perennial and diffuse (Western Pennsylvania Conservancy 1998).

The Marysville seeps and the entire valley are forested; in July 2011 the most abundant species in the canopy were *Tsuga canadensis, Pinus strobus, Betula lenta, Liriodendron tulipifera, Fraxinus nigra, Fagus grandifolia, Nyssa sylvatica* and *Acer rubrum*; in the understory: *Carpinus caroliniana, Cornus florida,* and *Fagus grandifolia*. Shrubs included *Staphylea trifolia, Lindera benzoin, Hamamelis virginiana, Viburnum dentatum,* and *Ilex verticillata;* vines: *Toxicodendron radicans, Parthenocissus quinquefolia,* and *Smilax herbacea*. The herbaceous layer was thick and included the following species: *Anemone acutiloba, Anemone quinquefolia, Aralia nudicaulis, Aralia racemosa, Brachyelytrum erectum, Circaea canadensis, Deparia acrostichoides, Goodyera pubescens, Huperzia lucidula Maianthemum canadense, Maianthemum racemosa, Medeola virginiana, Mitella diphylla, Platanthera clavellata, Platanthera orbiculata, Polemonium reptans, Podophyllum peltatum, Polygonatum pubescens, Polystichum acrostichoides, Thelypteris noveboracensis, Uvularia sessilifolia,* and *Viola labradorica* (A. Rhoads, personal observation).

The following species were growing in the seepage areas in close proximity to *E. purpurea*: *Arisaema triphyllum, Boehmeria cylindrica, Carex prasina, Chrysosplenium americanum, Ilex verticillata, Impatiens capensis, Lindera benzoin, Onoclea sensibilis, Osmunda cinnamomea, Osmunda regalis, Symplocarpus foetidus, Thalictrum pubescens,* and *Viburnum dentatum.* A small population *of Trillium cernuum* (proposed Pennsylvania threatened) was present in one area.

Data collected between 1995 and 2012 reveal an initial period of four years when the total number of stems fluctuated between 1695 and 1919. However, since 1998 stem number has declined steadily from 1746 to 667 in 2012, a 62 percent decrease (Figure 17). The total number of plants has followed a similar trajectory, after fluctuating between 937 and 823 between 1995 and 1999 the total declined steadily to a low of 279 in 2013 (Carol Loeffler, unpublished data).

No deer exclosures have been erected at Marysville. But despite occasional nipped off stems, Carol Loeffler believes that succession, resulting in increased shading, is a more significant factor in the decline (C. Loeffler, personal communication, 7/12/2011).



Fishing Creek, Lancaster County

Historically there were two populations of *E. purpurea* in the valley of Fishing Creek, a tributary of the Susquehanna River. Site one was documented in 1952 by Emma Groff who deposited a specimen at the herbarium at Franklin and Marshall College (Table 1). Attempts to relocate that population have not been successful.

The second Fishing Creek site is in a west-facing, mixed hardwood forest with numerous seepage areas; it has been monitored since 2007 by Pennsylvania Natural Heritage Program staff. In 2007 the population contained 10 *E. purpurea* clumps (plants?) with a total of 58 stems including some with flowers or fruits; in 2010, only 28 stems, all vegetative, were recorded (Table 2). In 2012 the total was 3 clumps with a total of 16 stems; none had evidence of flowers or fruits on May 16.

Table 2. *Euphorbia purpurea* census data for Fishing Creek seeps

Source: PNHP and personal observation 5/16/2012

year	*clumps (plants)*	*total stems*	*fertile stems*
2007	10	58	+
2010		28	0
2012	3	16	0

This site is underlain Peters Creek Schist; a metabasalt dike is also present (PA Bureau of Topographic and Geologic Survey 2001). Associated flora included a canopy dominated by *Liriodendron tulipifera, Acer rubrum,* and *Nyssa sylvatica*. Understory species included *Lindera benzoin, Ilex verticillata, Hamamelis virginiana, Sambucus canadensis, Acer negundo, Parthenocissus quinquefolia, Toxicodendron radicans,* and non-native, invasives *Rubus phoenicolasius* and *Lonicera japonica*. The herbaceous layer contained *Symplocarpus foetidus, Impatiens capensis, Osmunda cinnamomea, Onoclea sensibilis, Polystichum acrostichoides, Arisaema triphyllum, Viola cucullata, Carex leptalea*; and the non-natives: *Alliaria petiolata, Glechoma hederacea,* and *Duchesnia indica* (PNHP 2011).

Bryansville Station, York County

Euphorbia purpurea was first collected near Bryansville in 1959 by Edgar T. Wherry (Table 1). This extant site consists of a small open seepage area along an abandoned railroad grade. Located on a slope overlooking Muddy Creek, the seep is surrounded by hemlock-hardwood forest. It has been monitored by Pennsylvania Natural Heritage Program staff since 1992. In that year the site contained 14 clumps with 145 stems of which 24 contained fruits (Table 3). In 1996 the *E. purpurea* stand consisted of 150 stems, nine with fruit. The presence of two juvenile plants provided evidence of successful reproduction (PNHP 2011). In 2012 only two clumps were seen; one above the railroad grade with 32 stems including two with flowers and fruits, and one below with seven stems two of which had been nipped off.

Table 3. *Euphorbia purpurea* census data for Bryansville Station Seep

Source: PNHP and personal observation 5/16/2012

year	*clumps (plants)*	*total stems*	*fertile stems*
1992	14	145	24
1996	12	150	9
2012	2	37	2

In 2012 the open seepage area where *E. purpurea* was growing was approximately 10 m in diameter. Associated herbaceous flora included *Symplocarpus foetidus, Osmunda cinnamomea, O. claytoniana, Deparia acrostichoides, Impatiens capensis, Ranunculus recurvatus, Arisaema triphyllum, Chelone glabra, Persicaria arifolia, Collinsonia canadensis* and *Festuca obtusa*. Several non-native invasive species were also present in the seep: *Poa trivialis, Microstegium vimineum, Glechoma hederacea,* and *Duchesnia indica*. The seep also contained *Ilex verticillata, Alnus* sp., *Hamamelis virginiana* and a young *Juglans nigra*. Surrounding trees included *Tsuga canadensis, Liriodendron tulipifera*, and *Betula allegheniensis* (A. Rhoads, field notes May 2012).

This site is underlain by Octoraro Formation schist (PA Bureau of Topographic and Geologic Survey 2001; USGS 2012).

Status of *Euphorbia purpurea* in Other States

Delaware

Euphorbia purpurea is ranked critically imperiled (S1) in Delaware. There is a single extant population located on the Coastal Plain in Kent County. The population is small, only 4 plants; habitat is a groundwater seep at the base of a moderate slope within a stream corridor.

Additional specimens collected in the late 1800's and early 1900's document several historical occurrences in New Castle County in the Piedmont Physiographic Province. However, repeated searches of those areas in recent years have been unsuccessful (W. McAvoy, personal communication, March 27, 2012).

Maryland

Euphorbia purpurea is classified critically imperiled (S1) in Maryland (Maryland Natural Heritage Program 2010). Historically it is known from five counties; it is believed to be extirpated in two of those (NatureServe 2012).

All known populations are in Cecil (1), Frederick (3), and Harford (2) Counties (Table 4) in northeastern Maryland in the Piedmont upland and Piedmont Lowland Physiographic Provinces (Figure 4). Recent populations range in size from 10—200 plants.

Table 4. *Euphorbia* purpurea sites in Maryland
Source: Maryland Natural Heritage Program 2012

county	*date last seen*	*population at most recent survey*	*habitat*
Baltimore	pre-1910		
Carroll	1940		
Cecil	1869		
Cecil	1905		
Cecil	1925		swampy woods
Cecil	1928		woods
Cecil	1991	19 plants	mesic deciduous forest
Frederick	1960		side of railroad tracks, looked for extensively in1985 but not found
Frederick	1986	1—10 plants	slope with saturated soil and partial shade
Frederick	2006	10 plants	semi-open wet meadow, old pasture
Frederick	2007	31 plants	circum-neutral wetland complex with seepage slopes, wet meadows and forested swamp; sun exposure open to filtered
Harford	1996	40 stems	steep, rocky, wooded, west-facing seep
Harford	1996	200 plants	seepage swamp in steep rocky ravine

New Jersey
Euphorbia purpurea is currently classified as critically imperiled (S1) in New Jersey; it is also protected under the Pinelands Commission and the Highlands Water Protection and Planning Act (New Jersey Natural Heritage Program 2012).

Early collections of *E. purpurea* from Salem and Cape May Counties from 1895—1946 had not been seen for almost 40 years and the species was thought to be extirpated in New Jersey. But in 1985 a population of approximately 200 plants in two subpopulations was discovered growing in mucky seeps along a small stream in Cape May County in the Coastal Plain Physiographic Province (Snyder 1986). This is apparently the same site documented by botanists Bayard Long in 1919 and Witmer Stone in 1920. Associated species included *Carex mitchelliana, Caltha palustris, Chrysosplenium americanum, Cirsium muticum, Sphenopholis pensylvanica,* and *Viola labradorica*. This population is persisting as the only known extant stand *of E. purpurea* in New Jersey; ongoing searches of all other historical locations and additional areas of suitable habitat have failed to reveal additional plants (D. Snyder, personal communication, March 27, 2012).

North Carolina
In the 1960s *E. purpurea* was known from three counties in the mountains of northwestern North Carolina where it was described as rare in low woods (Radford et al. 1968). More recently, populations have been discovered in nine additional counties, but two of the original populations have become extirpated (Buchanan and Finnegan 2010). All sites, current and extirpated, are in the Blue Ridge Physiographic Province of western North Carolina (Figure 4).

Ohio
Euphorbia purpurea is classified critically imperiled (S1) by NatureServe (2011) and endangered by the Ohio Department of Natural Resources (2012). Although several historical (pre-1940) sites were known, the plant was thought to be extirpated until a population consisting of approximately 75 plants was discovered in Pike County in 1987 (Knoop 1990). Despite the fact that *E. purpurea* is typically found in saturated soils of headwaters seepage areas, at this site it is growing on a steep north-facing slope underlain by Peebles dolomite. Associated species include *Quercus muhlenbergii, Q. rubra, Fraxinus quadrangulata, Celtis occidentalis, Viburnum prunifolium, Hydrangea arborescens, Aquilegia canadensis, Carex eburnean,* and *Asplenium ruta-muraria* (Knoop 1990).

Virginia
Euphorbia purpurea is classified imperiled (S2) in Virginia (Townsend 2009). There are 19 known populations in the state, 10 of which have been observed since 2000 (Table 5). The sites are spread over nine counties in the Ridge and Valley, Northern Blue Ridge and Southern Blue Ridge Physiographic Provinces (Figure 4) (Virginia Natural Heritage Program 2012).

Habitats include forested floodplain of the Clinch River; floodplain pasture; wet meadow; steep, rocky wooded slopes above the Clinch River; mixed deciduous forest; edge of calcareous fen/seep; high elevation *Fraxinus pennsylvanica* seepage swamp, and a successional old field on the upper slope of Russell Beartown Mountain. Geological substrates include limestone, dolomite, and gneiss.

Table 5. *Euphorbia purpurea* sites in Virginia
Source: Virginia Natural Heritage Program (2012)

year last seen	*sites*	*population size range*
1940	1	no count
1980—1989	4	30—150
1990—1999	4	8—several thousand
2000 and later	10	1—3,500

Approximately 75 percent of the sites are on lands owned and managed by federal or state agencies including U.S. Forest Service, National Park Service, Virginia Department of Conservation and Recreation, and Virginia Department of Game and Inland Fisheries. The rest are privately owned.

Threats cited include deer browsing, gypsy moth damage to the forest habitat, logging, quarrying, trampling by cattle and hikers, trail enlargement, canopy closure, and invasives (*Alliaria petiolata* and *Microstegium vimineum* specifically mentioned) (Virginia Natural Heritage Program 2012; Ogle 1989).

West Virginia
Euphorbia purpurea is classified imperiled (S2) in West Virginia (West Virginia Natural Heritage Program 2007). It occurs at 15 sites ranging in elevation from 1223 to 4100 feet above mean sea level along the Allegheny Mountains Section of the Appalachian Plateau Physiographic Province and the Allegheny Front in eastern West Virginia (Table 6; Figure 4) (West Virginia Natural Heritage Program 2012; West Virginia Geological and Economic Survey. 2012).

Geological substrates mentioned include sandstone, Greenbrier limestone, and Mauch Chunk Formation; soil textures include: silty clay, sand and loam, silt loam, loam (West Virginia Natural Heritage Program 2012).

Euphorbia purpurea is a component of ***Balsam fir – black ash swamp***, a critically imperiled community type in West Virginia. It is a late successional, patchy vegetation type that is seepage fed; microtopography includes tip-up mounds and irregular hummocks. Other woody plants include *Picea rubens, Tsuga canadensis, Betula allegheniensis Ilex verticillata, and Alnus incana ssp. rugosa* and *Rhamnus alnifolia.* Additional herbaceous species include *Carex bromoides, C. crinita, Geum rivale,* and *Polemonium van-bruntiae* (Byers et al. 2007; Rentch et al. 2008).

The range of habitats of *E. purpurea* also includes open, wet bottomland; wet swale in oak-maple forest; alder thickets; successional hawthorn savannah; acidic seepage wetland (West Virginia Natural Heritage Program 2012). .

In addition, several large populations are growing in pastures or former pastures where suppression of competing vegetation by cattle has allowed *E. purpurea* to thrive. In this open

habitat, *E. purpurea* does not grow as tall as it does in shaded or semi-shaded locations and the proportion of flowering stems is higher. High precipitation and frequent fog may compensate for the fact that the pasture sites are not typically wetlands (NatureServe 2011).

Table 6. *Euphorbia purpurea* sites in West Virginia
Source: West Virginia Natural Heritage Program 2012

county *(northeast to southwest)*	***date last seen***	***number of plants at most recent survey***	***elevation in feet***	***habitat description***
Preston	1977	several	2000	roadside, broken canopy, average wetness
Preston	1992	3	2560	wet swale in oak-maple forest
Tucker	1996	20	3200	wetland with spruce, alder, swamp rose, *Carex*, etc.
Tucker	1997	2+	3230-3240	alder thicket with herbaceous understory
Tucker	2002	thousands	3230-3245	acidic seepage wetland in open woodland
Tucker	2005	800+	3150-3400	old field, pasture, wet meadow
Randolph	1986	thousands	3560-3840	steep, well-drained limestone pasture; open wet bottomland
Randolph	1994	not given	2800	wetland in bend of river
Randolph	1998	abundant	3000-3240	streamside and periodically inundated shrub floodplain
Randolph	2008	100	3480	narrow seep surrounded by open pasture
Randolph	2010	65	3380-3390	successional hawthorn savannah on floodplain (old pasture)
Pocahontas	1991	134	4100	mesic forest seep with sugar maple and beech
Pocahontas	2004	1% plot cover	1223	yellow birch- sugar maple- spruce-*Carex. scabrata* seep
Pocahontas	2009	9	3600-3635	alder shrub swamp and wet meadow (grazed prior to 1999)
Greenbrier	2008	1 clump	4040-4050	high elev. deciduous forest –regenerating post logging and fire

Threats mentioned include over-grazing and trampling by cattle, grazing by deer, and competition from invasive species including *Iris pseudacorus* and *Rubus phoenicolasius*.

Critical Management Issues

Declining Population Size

Numbers of plants and stems have declined at all but two of the *E. purpurea* populations. The exceptions are both fenced sites. At Cowans Gap, where exclosures were erected in 2000, both stem number and plant number have increased; some of the increase is due to off-site seedling production followed by transplanting (C. Loeffler, personal communication). At Hunters Run, fenced since 2002, plant number has declined but stem number has stabilized or increased slightly. All other sites, fenced or unfenced, have undergone large decreases in number of both plants and stems (Table 7).

Table 7. Population Trends at Pennsylvania Sites

	genets/ramets		*genets*	*ramets*	
site	*earliest data*	*2011-12*	*change*	*change*	*fenced*
Bryansville Station	14/145 (1992)	2/37	-86%	-74%	no
Fishing Creek	10/58 (2007)	3/16	-70%	-72.5%	no
Cowans Gap S. P.	12/12 (2000)	14/67	+117%	+558%	yes
Mount Holly Marsh	61/70 (1995)	8/28	-87%	-60%	yes
Hunters Run	30/44 (1995)	21/46	-27%	+105%	yes
Goat Hill	140/335 (2001)	69/180	-50.7%	-47%	partial
Marysville (Lambs Gap)*	844/1746 (1995)	279/667	-66.9%	-62%	no

* Marysville is the only site at which there has been no habitat manipulation

Possible Contributing Factors

Life history traits **-** *Euphorbia purpurea*, consistent with its categorization as a K-selected species, has evolved a life history strategy of long-lived plants with a low rate of sexual reproduction. The demographic data presented in Figures 9, 11, and 15 show that the majority of plants in all populations are mature, non-flowering individuals. Loeffler and Wegner (2000) reported that less that 7 percent of the plants studied flowered each year during their initial four-year study. This may be normal population demographics for *E. purpurea*.

Pollination limitation **-** Low fruit set and failure of fruits to mature in some locations suggests that pollination may also be a limiting factor in small scattered populations. Questions that need to be answered include: What pollinates *E. purpurea*? Are the plants self-fruitful? Could patchy distribution and low numbers of flowering stems in forested sites be restricting opportunities for successful pollination?

Recruitment **-** Germination and seedling recruitment rates are also low. *In situ*, less than 10 percent of seeds produce seedlings, and many seedlings do not reappear after their first year (Figures 9, 11, and 15) thus there is little or no opportunity for recruitment of new reproductive individuals. This problem is especially acute in small populations. Even in the fenced population at Hunters Run, the trend has been a decrease in the number of plants (Figure 13), but stabilization in the number of stems (Table 7).

Inbreeding depression **–** Another factor leading to the decline of *E purpurea* may be genetic constraints in the form of inbreeding depression. Loss of genetic diversity is always a possibility

in a species that exists only in small, widely separated populations. It could be that species that become rare for some other reason, especially those with inherently slow rates of reproduction, enter a downward spiral of increasing genetic load begetting smaller populations begetting even more genetic load, etc.

The role of disturbance - Anecdotal evidence suggests that periodic disturbance may be an important characteristic of the habitat of *E. purpurea*. A life history dominated by long-lived plants with limited investment in reproduction, may allow established plants to survive long periods when conditions do not favor flowering and seed production. When a localized disturbance such as a tree-fall, defoliation, fire, etc. creates an opening in the canopy they can respond quickly through increased flowering and seed production.

Marysville, the largest existing Pennsylvania population and the only site that has not been manipulated, may provide an opportunity to learn more about the role of disturbance. The population area is large enough that controlled and replicated treatments could be established to address some of these questions.

We know that *E. purpurea* has been present at Marysville since 1962 (Table 1). In reality, it has almost certainly been there much longer. Although we have 18 years of census data, this period represents a small window in the existence of the Marysville population. Disturbance cycles important to this species may operate over longer time spans. In forested sites such as Marysville, the challenge is to understand what disturbance events are (or were) present that may have helped create favorable environmental conditions over time.

Historical aerial photography of the Marysville *E. purpurea* site (PennPilot) shows an intact canopy in 1938; in 1958 some canopy removal was evident at the western end of the population area. By 1971, the canopy again appeared intact throughout.

Lidar data (PASDA 2012) for the site reveals that the tallest canopy trees are present along the stream corridor, compared to the adjacent slopes. This is also where *E. purpurea* is found. Furthermore, the eastern half of the *E. purpurea* population area has a denser canopy than the western half due to the presence of conifer species (*Tsuga canadensis* and *Pinus strobus*). Coincidentally, the easternmost sub-population of *E. purpurea* is small, consisting of only three to fivel plants (Carol Loeffler, unpublished data).

Table 8. Natural, Historical, and Anthropogenic Sources of Disturbance

natural sources of disturbance	historical sources of disturbance	anthropogenic sources of disturbance
wild fire	fire (Native Americans)	controlled burns
natural tree death	trampling by bison and elk	logging
defoliation by insects	passenger pigeon roosts	selective canopy thinning
deer browse		
ice and wind storms		
flooding		

Deer browse – Herbivory by deer occurs regularly in Pennsylvania. The proportion of stems browsed in monitored Pennsylvania populations of *E. purpurera* varies from 5 to 65 percent (Loeffler and Wegner 2000; C. Loeffler unpublished data).

While not usually fatal, browsing has a disproportionate impact on flowering and fruiting. Deer typically remove the stem apex of the larger stems, preventing flowering and seed production. Browsed stems cease further growth for the season (Loeffler and Wegner 2000).
In Pennsylvania, fencing appears to have allowed several small populations, such as those at Cowans Gap and Hunters Run, to increase their reproductive effort.

However, an exclosure at Goat Hill, while apparently slowing the decline in plant number, compared with the total Goat Hill population, has not led to increased reproduction (Figure 16).

Figure 18. *Euphorbia purpurea* showing effects of browsing by deer, photographed at the Marysville (Lambs Gap) site in Pennsylvania 7/15/2011.

Deer browse has been cited as a cause of decline in *E. purpurea* populations in Virginia (Virginia Natural Heritage Program 2012) and West Virginia (West Virginia Natural Heritage Program 2007).

Unlike deer, cattle are apparently deterred by the acrid latex *E. purpurea* contains; large populations in Virginia and West Virginia occur in cattle pastures.

Although deer browse has been reported in Ohio, it is not considered a management concern (Ohio Natural Heritage Program 2012).

Herbivory by insects - Observations in Pennsylvania indicate negligible damage to *E. purpurea* by herbivorous insects (Loeffler and Wegner 2000). However, concern has been voiced that root-mining flea beetles in the genus *Aphthona* imported to control *Euphorbia esula*, an invasive, non-native plant from Eurasia that is widely naturalized in North America, may constitute a threat to *E. purpurea* (New Jersey Natural Heritage Program 2008). Pemberton and Rees (1990) evaluated host specificity of *Aphthona flava* Guill. in feeding trials that included *Euphorbia purpurea* and five other North American members of the subgenus *Esula*. Three

species supported full development of *A. flava* from egg through adult. *Euphorbia purpurea* and two others appeared not to be suitable hosts as they supported only limited adult feeding but not larval development. However, further evaluation is needed as existing research has examined the feeding behavior of only one of the five species of *Aphthona* that have been introduced as biocontrol agents in the United States (Gassman et al. 1996).

Invasive species **-** Competition from invasive species including *Iris pseudacorus, Alliaria petiolata, Microstegium vimineum, Persicaria perfoliata,* and *Rubus phoenicolasius* is cited as a threat to *E. purpurea* in several states including Pennsylvania. The full impact of these plants has not been determined experimentally. In addition, *Symplocarpus foetidus*, a native plant that is a frequent associate in forested seepage areas, has been observed to suppress young seedlings of *E. purpurea* (Carol Loeffler, personal communication).

Conclusions

Stabilization of Existing Populations
In order to assure long term survival of *E. purpurea* in Pennsylvania it is essential to identify the critical environmental factors that maintain favorable habitat and allow them to proceed.

We suggest exploring the feasibility of establishing a series of controlled and replicated plots at Marysville to evaluate the relative importance of excluding deer and thinning the canopy on *E. purpurea* plant and stem number and reproductive effort.

Establishment of New Populations
Once we have a better understanding of critical environmental factors, potential sites for establishment of new populations can be explored. Given the limited dispersal potential of *E. purpurea*, it is likely that historically this plant has not reached all Pennsylvania locations where suitable habitat exists.

If Pennsylvania populations are found to have reduced genetic diversity, introduction of propagules from elsewhere in the range of the species should be explored.

Measures of Success

- All seven existing populations stable or increasing
- Establishment of two new populations

Research Needs

- What are the critical environmental factors that determine where *Euphorbia purpurea* grows?
- What are the pollinators of *Euphorbia purpurea*?
- Is *Euphorbia purpurea* self-fruitful?
- How long can seed remain viable in the soil? What is the seed banking potential?
- How long do individual *E. purpurea* plants live?
- What can we do to increase the percentage of seedlings that survive to become mature reproductive plants?
- Do Pennsylvania populations of *E. purpurea* exhibit inbreeding depression?
- Are non-native, invasive plants such as *Microstegium vimineum* and *Persicaria perfoliata* interfering with establishment and growth of *E. purpurea* seedlings?
- The issue of successional growth causing a decline in vigor and flowering of *E. purpurea* must be addressed if this plant is to remain part of the extant flora of Pennsylvania. Is deliberate thinning of the canopy, understory, and/or shrub layers an effective strategy in the absence of natural community dynamics?

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Appendix A. Site Visits Conducted During Preparation of this Report

Perry County
Marysville (Lambs Gap) July 15, 2011, Ann Rhoads and Carol Loeffler

Cumberland County
Hunters Run, July 15, 2011, Ann Rhoads and Carol Loeffler

Chester County
Goat Hill Serpentine Barrens, July 22, 2011, Ann Rhoads and Carol Loeffler

York County
Bryansville Station, May 16, 2012, Ann Rhoads, Tim Block, John Kunsman and Stephanie Seymour

Lancaster County
Fishing Creek, May 16, 2012, Ann Rhoads, Tim Block, John Kunsman, and Stephanie Seymour