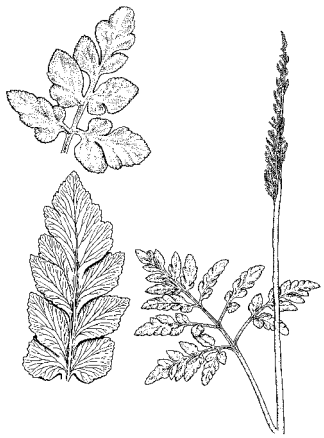
Conservation Assessment

for

Blunt-lobe Grapefern (Botrychium oneidense)



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This Conservation Assessment was prepared to compile the published and unpublished information and serves as a Conservation Assessment for the Eastern Region of the Forest Service. It does not represent a management decision by the U.S. Forest Service. Though the best scientific information available was used and subject experts were consulted in preparation of this document, it is expected that new information will arise. In the spirit of continuous learning and adaptive management, if you have information that will assist in conserving the subject community, please contact the Eastern Region of the Forest Service - Threatened and Endangered Species Program at 310 Wisconsin Avenue, Suite 580 Milwaukee, Wisconsin 53203.

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EXECUTIVE SUMMARY

Botrychium oneidense is a small fern within *Botrychium* subgenus *Sceptridium* (grapeferns), recognized as a distinct species only since 1961. It is found across the northeastern United States to the Great Lakes region and adjacent Canada. The habitat is somewhat variable, with plants usually in moist forests. In the Great Lakes region, plants are often in wet depressions within rich mesic forests. Occasionally plants occur open areas. Timber harvest and hydrologic disruption are likely the greatest potential threats to the species' habitat. Exotic earthworms may also be a threat. Details about the biology of *B. oneidense* are mostly generalized from studies of other *Botrychium* species; little information is available specifically for *B. oneidense*. Grapeferns are considered long-lived perennials, with much of the life-cycle occurring underground. Like other species of *Botrychium*, *B. oneidense* is dependent on a mycorrhizal relationship; thus species conservation must include consideration of this relationship. No information is available on managing habitat to maintain the species. Since plants are small and population numbers fluctuate from year-to-year, continued inventory efforts are necessary to better refine population demographics, range, and habitat. In addition, much basic information on the ecology of *B. oneidense* biology is lacking.

INTRODUCTION/OBJECTIVES

One of the conservation practices of the USDA Forest Service is designation of Regional Forester's sensitive species. The Eastern Region (R9) of the Forest Service updated its Sensitive Species list on February 29, 2000. Part of that process included identification of priority species for Conservation Assessments and Strategies. A group of *Botrychium* species (Ophioglossaceae; Adder's-Tongue Family) was one of those priorities.

The objectives of this document are to:

1. Provide an overview of current scientific knowledge for *Botrychium oneidense*.
2. Provide a summary of the distribution and status of *Botrychium oneidense*, both rangewide and within the Eastern Region of the USDA Forest Service.
3. Provide the available background information needed to prepare a subsequent Conservation Strategy.

The genus *Botrychium*, family Ophioglossaceae, are ferns that are typically divided into three subgenera in North America (Lellinger 1985). One subgenus, *Osmundopteris*, is only represented in our area by *B. virginianum*, the rattlesnake fern, which is common around the world (Wagner 1998). The subgroup *Botrychium*, the moonworts, includes numerous species of often rare, local, and very small plants that are difficult to find and identify. The subgenus *Sceptridium* are the grapeferns, medium-sized plants, and while often termed 'evergreen,' a more appropriate term might be 'wintergreen' since the old frond dies the following spring. Like the moonworts, the grapeferns (and especially *B. oneidense*), have had a confused

taxonomy in the past. *B. oneidense* was considered a form or variety of several other species until it was eventually recognized as a distinct species in 1961 (Wagner 1961a).

B. oneidense is one of the larger grapeferns, sometimes growing to more than 30 cm in height. Rangewide, its typical habitat is wet, shady woods and swamps across northeastern North America (Lellinger 1985). It occasionally occurs in open fields (Wagner 1960b). In the Great Lakes region, *B. oneidense* is found in a variety of habitats but wet depressions in northern hardwood forests are most common (USDA Forest Service, Eastern Region 1999).

There is little specific information about many aspects of *B. oneidense* life history and ecology.

NOMENCLATURE AND TAXONOMY

- Scientific Name: *Botrychium oneidense* (Gilbert) House
- Family: Ophioglossaceae; Adder's-Tongue Family
- Common Name: Blunt-Lobe Grapefern
- Synonymy: *Botrychium dissectum* Spreng. var. *oneidense* (Gilbert) Farw.; *Botrychium multifidum* (Gmel.) Trev. var. *oneidense* (Gilbert) Farw.

DESCRIPTION OF SPECIES

General description and identification notes

B. oneidense is perennial fern that bears a single pinnate frond (sterile blade) and a fertile blade. The fertile blade is often not present (Cody and Britton 1989). Like many species of *Botrychium*, *B. oneidense* often occurs with other plants of the same genus (Wagner and Wagner 1983). Young plants of *B. oneidense* can look like two of these, *B. dissectum* or *B. multifidum* (Wagner and Wagner 1993). *B. oneidense* differs from *B. multifidum* by having unequally divided leaf segments: the terminal segments are more elongate and less divided than the lower segments. In *B. multifidum*, the leaf segment area is about the same size and shape. The distinctions between *B. oneidense* and *B. dissectum* are more subtle:

- Roots of *B. oneidense* are pale gray to tan with diameters of roots located 1 cm from the stem averaging 2.5 mm in living plants. *B. dissectum* roots are usually dark gray-brown roots with root-diameters averaging 3 mm in living plants.
- Leaf-segments of *B. oneidense* are more or less rounded at the tips while those of *B. dissectum* are somewhat pointed.
- Young leaves and overwintering leaves of *B. oneidense* are mostly green while leaves of *B. dissectum* are reddish when young and often bronze-colored in winter (Wagner 1961a).

New leaves appear in *B. oneidense* during late May. There is a seasonal sequence in leaf development among several species of *Botrychium* (Wagner and Wagner 1982): *B. multifidum* develops first followed by *B. oneidense, B. rugulosum* and *B. dissectum*. Since the

leaves of most *Botrychium* spp. develop slowly, earlier species will have leaves that are noticeably more developed than later species. Late summer or early fall is the best time to survey for the species, coinciding with maximum leaf development (USDA Forest Service 2000).

A key to identify individuals within *Botrychium* subgenus *Sceptridium* (grapeferns, which includes *B. oneidense*, *B. multifidum*, *B. rugulosum*, and *B. dissectum*) is presented by Wagner and Wagner (1982). The treatment in Volume 2 of the Flora of North America (Wagner and Wagner 1993) is the most current published guide to all but the most recently described species (for example, since the release of Volume 2, a new species, *Botrychium linear*e, has been described by Wagner and Wagner [1994]). Lellinger (1985) includes descriptions and color photographs of many moonwort species. Cody and Britton (1989) provide descriptions and distribution maps of *Botrychium* species known to that time in Canada.

Technical description

Trophophore stalk 2-15 cm, 1.5-2.5 times the length of the blade rachis; blade dull bluish green and overwintering, 2-3 pinnate, to 15 x 20 cm, leathery; pinnae to 5 pairs, usually remote, horizontal to ascending, distance between first and second pinnae not or slightly more than between second and third pairs, undivided except in proximal 2/3-3/4. Pinnules obliquely ovate, margins finely crenulate to denticulate, apex rounded to acute, venation pinnate; sporophores 2-3 pinnate, 1.5-2.5 times length of trophophore. 2n=90 (after Wagner and Wagner 1993).

LIFE HISTORY

B. oneidense belongs to subgenus *Sceptridium* (grapeferns) within the genus *Botrychium*. In North America there is also subgenus *Osmundopteris* (rattlesnake ferns) and subgenus *Botrychium* (moonworts) (Lellinger 1985, Wagner and Wagner 1993). The life-cycle of all three subgenera is similar (Lesica and Ahlenslager 1996). Grapefern trophophores are present during the winter, while moonwort and rattlesnake fern leaves die back by winter. The plants have both a trophophore (vegetative segment) and a sporophore (fertile segment). Moonworts are generally smaller than rattlesnake ferns and grapeferns.

Like all ferns, grapeferns are characterized by alternation of generations between sporophytes and gametophytes. The sporophyte, the diploid (2N) generation of the plant, begins its life after fertilization of an egg by a sperm within the archegonium of the gametophyte. Embryology of *Botrychium* species has been little studied due to the difficulty of obtaining suitable material (Gifford and Foster 1989, Mason and Farrar 1989). Early morphological studies (e.g., Campbell 1922) described a diversity of patterns of embryo development among *Botrychium*. For example, *Botrychium simplex* has a relatively large cotyledon and rapid development, perhaps capable of maturing a small aboveground fertile frond in its first year, while *B. lunaria* has a relatively small cotyledon, and may take as much as seven years to produce an emergent frond.

The following information is from research on a number of *Botrychium* species. Reproduction in *B. oneidense* has not been researched and there may be life history details specific to *B. oneidense* that do not follow these general patterns typical in the genus. Lack of specific information on the life history of *B. oneidense* is an impediment to management of habitats where this species occurs.

Vegetative reproduction was not thought to occur in *Botrychium* (Wagner et al. 1985), but Farrar and Johnson-Groh (1990) have documented underground gemmae (bud-like structures) in a few species of moonwort. There have been no reports of gemma production in *B. oneidense*, and the primary mode of reproduction is likely sexually through spores.

The spore cases of *Botrychium* are among the largest of all known ferns, and appear like clusters of tiny grapes (hence the name *Botrychium*, from *botrus*, Greek for grapes) (Wagner 1998). The number of spores per case is probably the highest known for vascular plants, numbering in the thousands (Wagner 1998). In most species the sporangial opening to release the spores is over 90° between the two sides of the gap (Wagner 1998). The spores have been measured to disperse by wind about one meter (Hoefferle 1999), but may potentially travel much less, perhaps only a few centimeters from the parent (Casson et al. 1998). Peck et al. (1990) found that *B. virginianum* spores landed within 3 m of the source if the plant was above the herbaceous layer, but much less when the sporophore was within the herbaceous layer. While most spores could be expected to land near the parent plant, some may travel considerable distances (Wagner and Smith 1993, Briggs and Walters 1997).

The succulent nature of the plant, the questionable spore dispersal mechanism, and the very thick spore walls (Wagner 1998) that could help the spores to pass through an animal's gut, have suggested to some that herbivores, such as small mammals, may be involved in dispersal (Wagner et al. 1985, Wagner and Wagner 1993). The sporangia may also simply rot in the ground, thereby dispersing their spores (NatureServe 2001). It is uncertain how long *Botrychium* spores will remain viable (Lesica and Ahlenslager 1996).

After the spores are released, they infiltrate into the soil and may germinate. Infiltration and subsequent germination may take up to 5 years, although some may germinate immediately (Casson et al. 1998). Spore germination requires darkness, (Whittier 1972, 1973; Wagner et al. 1985), a requirement that is not surprising in view of the subterranean habitat of the gametophyte and the need for the resultant gametophyte to be infected by an endophytic fungus in an obligate association (Whittier 1973). Details of this host/fungus interaction are provided in Schmid and Oberwinkler (1994). It has been suggested that *Botrychium* gametophytes may even delay growth until they are infected with the fungus (Campbell 1911, Whittier 1973, Whittier 1996). Essentially the *Botrychium* gametophyte becomes a parasite of the mycorrhizal fungus (Casson et al. 1998, Whittier 2000). The underground gametophyte (subg. *Sceptridium*) is generally less than 0.3 cm in longest diameter, cylindrical or cushion shaped, moderately hairy, and light to dark brown-brown (Wagner et al. 1985).

All *Botrychium* species are believed to be obligately dependent on mycorrhizal relationships in both the gametophyte (Bower 1926, Campbell 1922, Gifford and Foster 1989, Scagel et al.

1966, Schmid and Oberwinkler 1994) and sporophyte generations (Bower 1926, Gifford and Foster 1989, Wagner and Wagner 1981). The gametophyte is subterranean and achlorophyllous, depending on an endophytic fungus for carbohydrate nutrition, while the roots of the sporophyte lack root hairs and probably depend on the fungus for absorption of water and minerals (Gifford and Foster 1989). *Botrychium* gametophytes were formerly considered saprophytic (Bower 1926), but are now thought to obtain carbohydrates fixed by neighboring plants and transported by shared mycorrhizal fungi (Camacho 1996); they are thus better classified as myco-heterotrophic (Leake 1994).

A fungal associate is present within the plant at the earliest stages of development of the gametophyte and sporophyte (Bower 1926). There are no reports of successful completion of the lifecycle by *Botrychium* species without fungal infection, however, the degree of infection may vary between species and age of plants (Bower 1926, Campbell 1922). Little is known about the mycorrhizal fungi associated with *Botrychium* species other than their presence within the gametophyte and roots of the sporophyte (Camacho 1996). *Botrychium* mycorrhizae have been described as the vesicular-arbuscular (VAM) type by Berch and Kendrick (1982) and Schmid and Oberwinkler (1994).

The mycotrophic condition is important to the ecology of *Botrychium* species in several ways. Nutrition supplied through a fungal symbiont may allow the ferns to withstand repeated herbivory, prolonged dormancy, or growth in dense shade (Kelly 1994, Montgomery 1990). The fungal/fern relationship has implications for the occurrence of genus communities, the distribution of the species across the landscape, and associations with particular vascular plants. Mycorrhizal links may explain the often observed close associations between certain moonworts and strawberries (*Fragaria* spp.; Zika 1992, 1994) and between grapeferns *(Botrychium* subgenus *Sceptridiu*m) and Rosaceous fruit trees (Lellinger 1985). Due to the occurrence of heterotrophic life-stages, moonworts share many of the morphological and habitat characteristics of myco-heterotrophic plants such as orchids (reviewed by Leake 1994) and in many respects behave much like mushrooms (Zika 1994).

Gametophytes and young sporophytes may exist underground for many years before an aboveground plant develops (Campbell 1911, Muller 1993). Mortality may be high during this period (Peck et al. 1990). The gametophyte produces male and female gametangia; fertilization of eggs occurs via free-swimming sperm under wet conditions (Lesica and Ahlenslager 1996). Most fertilizations are likely due to inbreeding, since the antheridia and archegonia are nearby and enzyme electrophoresis indicates a lack of genetic variability (McCauley et al. 1985, Soltis and Soltis 1986, Farrar and Wendel 1996, Farrar 1998). However, there is no reason that cross-fertilization should not occur, especially in consideration of the existence of interspecific hybrids (Wagner et al. 1985, Wagner 1998). McCauley et al. (1985) calculated that *B. dissectum* outcrosses about 5% of the time. Extremely high levels of inbreeding were also found in *B. virginianum* although there was evidence for some outcrossing (Soltis and Soltis 1986).

Sporophytes develop on the gametophyte, forming roots and a single leaf each season from a short rhizome (Foster and Gifford 1974). Root development occurs before any leaf development (Casson et al. 1998), and the roots must also be colonized by the mycorrhizal

fungi for a nutrient source (Farrar and Johnson-Groh 1990, Wagner 1998, Johnson-Groh 1998). The fungus involved is believed to be a vesicular arbuscular mycorrhizae (Berch and Kendrick 1982), which penetrates inside the plant cells of both the roots and the gametophytes in the case of *Botrychium* spp. The fungus may be transferring carbohydrates from other photosynthesizing plants in the vicinity, possibly species of herbaceous flowering plants (Farrar 1998). The species of mycorrhizae fungus involved with *Botrychium* is unknown (Casson et al. 2000). In a comparison of ferns and mycorrhizae colonization, the two *Botrychium* species surveyed had more extensively colonized roots than 37 other species of ferns (Berch and Kendrick 1982).

When the sporophyte eventually emerges, a sterile leafy blade (trophophore) and a fertile segment (sporophore) will develop. *Botrychium* plants may go dormant some years and not produce an aerial sporophyte (Wagner and Wagner 1981, Muller 1993). However, grapeferns (subgenus *Sceptridium*), may appear more regularly than moonworts (subgenus *Botrychium*) (Johnson-Groh, reported in USDA Forest Service, Eastern Region 1999). Species of *Botrychium*, with the exception of *B. mormo*, will not produce more than one sporophyte from a gametophyte within one growing season (Casson et al. 1998).

Several factors likely determine the size of the plant and how many spores it is capable of producing (Casson et al. 1998). These include the health of the plant and the associated fungi, climatic conditions, plant age, predators, and other factors. In discussing *B. mormo*, Casson et al. (1998) estimated that about 5–10% of aboveground plants will develop into larger plants with 20 to 50 sporangia (spore-bearing tissues) each.

Grapeferns differ from moonworts in that the fertile part of the plant may often be absent during a particular growing season (Wagner 1998). Leaves (trophophores) emerge in late spring to early summer (about mid-May in the Great Lakes area) for *B. oneidense* (Wagner and Wagner 1982). The evergreen trophophore persists through the winter (Wagner 1960b). In the spring the old leaf begins to decay and a new leaf begins to develop (Wagner 1960b). If the leaf is damaged soon after emergence, a second leaf may appear, at least in the closely related *B. dissectum* (Montgomery 1990). The loss of plants to herbivory, fire, and collection of aerial stems did not affect the return of moonwort species in later years (Johnson-Groh 1998, Johnson-Groh 1999). However, if grapeferns like *B. oneidense* depend relatively more on photosynthesis than the mycorrhizal relationship, as Johnson-Groh suggested in USDA Forest Service, Eastern Region (1999), then the loss of aboveground portions may have a more negative effect on the population.

Available information (Montgomery 1990, Muller 1993, Kelly 1994, Lesica and Ahlenslager 1996) indicates that members of subgenus *Botrychium* (moonworts) are short-lived perennials while subgenus *Sceptridium* (grapeferns) are more long-lived. Estimated half-life times for various grapeferns were 43.2 years (Montgomery 1990) and 11.2 years (Kelly 1994), while moonwort half-lives were 1.3 years (Muller 1993) and 3 years or less (Lesica and Ahlenslager 1996).

While numerous hybrids between different species of moonworts have been found (Wagner et al. 1985; Wagner 1991, 1993), there are no grapefern hybrids reported from North

America (Wagner 1993). Six of the seven grapefern species in North America are diploid with a chromosome number of 45, the seventh, *Botrychium jenmanii*, is the only tetraploid with n=90, a presumed ancient allopolyploid hybrid of two diploid species (Wagner 1993).

HABITAT

Across its range, *B. oneidense* is most common in low, wet, acid, second-growth woods and swamps (NatureServe 2001). It often occurs with *B. dissectum* which is a more common species and which occurs in more diverse habitats. Lellinger (1985) lists the habitat of *B. oneidense* as wet, shady woods and swamps. Wagner and Wagner (1993) describe the habitat similarly: moist, shady, acidic woods and swamps. In Canada, Cody and Britton (1999) describe *B. oneidense* habitat as rich moist woodland.

The 27 element occurrence records for Minnesota were primarily on level to gently sloping terrain in rich moist soil on the edges of depressions, ephemeral pools/vernal ponds, and other wetlands (USDA Forest Service, Eastern Region 1999). The occurrences were usually in northern hardwood forests dominated by *Acer saccharum* and *Tilia americana*. Other tree species included *Quercus* spp., *Acer rubrum*, *Fraxinus* spp., and *Populus tremuloides*. In most cases, there were only a few plants noted at each site, but one site in Cass County had hundreds of plants occurring in depressions in a second-growth hardwood forest composed of *Fraxinus nigra*, *Populus tremuloides*, *Acer saccharum*, and *Quercus rubra*. NatureServe (200) reported Minnesota habitats as shallow depressions and ephemeral pools in second-growth forests. Associated species include *Acer saccharinum, Allium tricoccum, B. lanceolatum* var. *angustisegmentum, B. multifidum, B. virginianum*, *Carex tuckermanii*, *Caulophyllum thalictroides*, *Fraxinus nigra*, *Hydrophyllum virginianum*, *Populus tremuloides*, *Quercus rubra*, and *Tilia americana*.

In northwestern Wisconsin, *B. oneidense* occurred in northern wet-mesic forest and northern dry-mesic forest (USDA Forest Service, Eastern Region 1999). NatureServe (2000) reported the following general Wisconsin habitats: Basswood and maple woods having moist depressions or boggy edges, and in second-growth woods; associated species of Botrychium include *B. lanceolatum* var. *angustisegmentum, B. matricariifolium*, and *B. virginianum*.

B. oneidense habitat preferences in other states are reported in NatureServe (2000) as:

Indiana: Low wet woods with peat or silt. One occurrence was on a floating mossy log in a buttonbush swamp. Associates included *B. dissectum*, swamp white oak, pin oak, sweetgum, and beech.

Kentucky: Second growth northern hardwood forest and grassy openings at higher elevations.

North Carolina: Rich coves, secondary growth, some areas with light-gaps from fallen trees. Associated with *Acer saccharum, Aesculus flava, Aplectrum hyemale, Aster cordifolia, Betula alleghaniensis, B. lenta, Botrychium dissectum, Carya cordiformis, Cimicifuga*

racemosa, Dicentra cucullaria, Hydrangea arborescens, Laportea canadensis, Liriodendron tulipifera, Pinus strobus, Trillium grandiflorum, and *Tsuga canadensis*.

New Jersey: Historically, known from widely scattered localities in seven counties outside of the pine barrens.

Ohio: Rich woods, stream terraces, northern and eastern aspects in oak/pine, and birch woods. Associated with *B. dissectum* and *B. multifidum*.

West Virginia: One site is characterized as under crab-apples on acid soils at the edge of a much used trail. There plants occur with *Asplenium platyneuron*, *Lycopodium digitatum*, and *Quercus palustris*.

DISTRIBUTION, ABUNDANCE, AND STATUS

Botrychium oneidense ranges from New Brunswick to Minnesota, south to North Carolina, Kentucky, Indiana, and Wisconsin.

North American range of *Botrychium oneidense* (Wagner and Wagner 1993).

U.S. and Canada State/Province Distribution

United States: Connecticut, Delaware, Indiana, Kentucky, Maine, Maryland, Massachusetts, Michigan, Minnesota, New Hampshire, New Jersey, New York, North Carolina, Ohio, Pennsylvania, Rhode Island, Vermont, Virginia, West Virginia, Wisconsin.

Canada: New Brunswick, Ontario, Quebec.

Global and state rankings were obtained from NatureServe (www.natureserve.org), a comprehensive online database of information on plants, plant communities, and animals. Conservation status ranks are defined in Appendix C.

Global Conservation Status Rank: G3 (1997)
Rounded Global Conservation Status Rank: G3

Global Conservation Status Rank Reasons: Due to the small stature and periodic emergence of this species, it is it easily overlooked. However, recent inventories (1995) have turned up over 40 new occurrences in Minnesota and Wisconsin. Previous alteration of this species' mature hardwood forest habitat has probably destroyed many sites; logging or other physical disruptions are likely to be detrimental.

United States: National Conservation Status Rank: N3 (1995)
Canada: National Conservation Status Rank: N1 (2000)

U.S. and Canada State/Province Conservation Status Ranks
United States: Connecticut (SR), Delaware (S1.1), District of Columbia (SX), Illinois (S1), Indiana (S3), Kentucky (S1), Maine (SU), Maryland (S1), Massachusetts (S1?), Michigan (S?), Minnesota (S1), New Hampshire (SR), New Jersey (S2), New York (S1S3), North Carolina (S1), Ohio (SR), Pennsylvania (SR), Rhode Island (SR), Tennessee (S1), Vermont (S1S2), Virginia (S2), West Virginia (S1), Wisconsin (S2)

Canada: New Brunswick (S1), Ontario (S3), Quebec (SH)

Appendix A lists 32 element occurrence records from Minnesota (the majority from Aitkin County), 19 from Wisconsin and 2 from Michigan (both from the Hiawatha National Forest). When numbers of plants within a population are given, they are usually low, typically numbering less than ten individuals at a given site.

GREAT LAKES STATES – NUMBER OF ELEMENT OCCURRENCES

State	No. of EOs	State Rank	Status	Comments
Minnesota	32	S1	E	State endangered
Wisconsin	19	S2	SC	State special concern
Michigan	2	(S?)	--	--
Total	53			

STATE and NATIONAL FORESTS - SUMMARY OF ELEMENT OCCURRENCES

National Forest	No. of EOs
Minnesota	32
Chippewa National Forest	1
Superior National Forest	0
Michigan	2
Ottawa National Forest	0
Hiawatha National Forest	2

Huron-Manistee National Forest	0
Wisconsin	19
Chequamegon-Nicolet National Forest	3
Total State EOs	53
Total National Forest EOs	6
NF as % of EOs in MN, WI, MI	11%

POPULATION BIOLOGY AND VIABILITY

Population studies on other species of moonworts have shown considerable annual variation in the number of aboveground plants at a given site (Johnson-Groh 1999). Populations fluctuated independently among plots at any given site, some populations may be increasing while others are decreasing (Johnson-Groh 1999). These variations reflect microsite differences such as soil moisture, herbivory, or mycorrhizae (Johnson-Groh 1999), although populations of moonworts are known to fluctuate wildly without any apparent cause (Johnson-Groh 1999). Individual plants may not emerge every year (Muller 1993, Johnson-Groh 1998).

Botrychium probably appear or disappear in accordance with mycorrhizal health (Johnson-Groh 1998) due to their obligate relationship with the fungi. Johnson-Groh (1999) concluded that mycorrhizae are the most limiting factor for *Botrychium* establishment, distribution and abundance. Environmental factors that may affect mycorrhizae, like reduction in water availability, are then also likely to have significant impacts on moonworts, whereas the repeated removal of leaf tissue may have little effect (Johnson-Groh 1999). Wagner and Wagner (1993) also concluded that taking many samples will have little effect on the population as long as the underground shoots and roots are left intact. Standard assumptions about the population biology of other more 'typical' plants may be irrelevant to *Botrychium* because of this obligate relationship (Johnson-Groh 1999).

Since there is considerable variation in the numbers of aboveground sporophytes, a measurement of only sporophytes does not completely indicate population numbers. Johnson-Groh (1998) developed a method to extract *Botrychium* gametophytes and belowground sporophytes from soil samples. Up to 7000 gametophytes and 250 non-emergent sporophytes per square meter of soil have been recovered, although an unknown number of these may be the common *B. virginianum* (Johnson-Groh 1998). In another report Johnson-Groh et al. (2000) found gametophyte populations ranging up to 2000 gametophytes/m^2 for some moonwort species; other moonwort species had a much lower density. Bierhorst (1958) reported finding 20 to 50 gametophytes of *B. dissectum* beneath each surface square foot with a predominance of younger gametophytes versus older ones with attached sporophytes. These findings suggest that a single emergent sporophyte may indicate a self-sustaining population at that site (Casson et al. 1998).

A spore-bank that consists of all ungerminated spores, including unopened sporangia, is present within the litter, duff, and soil (Casson et al. 1998). The spores persist in the soil for several years and, along with underground gametophytes and developing sporophytes, form a highly buffered moonwort population that can rebound from unfavorable years (Johnson-Groh et al. 1998, Johnson-Groh 1999). However, events that destroy the sporophytes, like an herbicide application, may have an effect several years later (Johnson-Groh 1999). These underground stages have been compared to seed-banks in angiosperms and likely play an important role in population dynamics (Kalisz and McPeek 1992).

A population model for the moonwort *B. mormo* has been developed by a working group within the Population and Habitat Viability Assessment effort (Berlin et al. 1998) and Johnson-Groh et al. (1998). This model uses a variety of input variables such as number of spores in the soil, number of soil gametophytes, frequency of catastrophes, etc. They concluded that populations subjected to increased levels of annual environmental variation are at greater risk of population decline and extinction, although a single catastrophic year has relatively little effect on simulated populations. The population is likely more stable than would be predicted from monitoring only aboveground plants due to the large proportion of the population in underground stages. *B. oneidense* may respond similarly.

Many species of *Botrychium* are associated with slight to moderate disturbances (Lellinger 1985, Wagner and Wagner 1993, Lesica and Ahlenslager 1996). However, *B. oneidense* is usually found in closed canopy forests with a less active disturbance regime.

POTENTIAL THREATS AND MONITORING

Threats to *B. oneidense* include drought, fire, timber harvest, collecting, herbicides, herbivory, exotic earthworms, succession, and grazing (USDA Forest Service 2000). Another source lists timber harvest and associated hydrologic changes in the wet habitats where *B. oneidense* often occurs (NatureServe 2001). USDA Forest Service, Eastern Region (1999) noted that any disturbance, such as timber harvesting, that would potentially reduce forest cover and alter moisture conditions could adversely affect populations of this species. An underlying management constraint is the lack of information available on the species.

Some of these threats will have their direct effect on the aboveground sporophyte and may be less serious, since the belowground part of the life-cycle is so important (see Sections C and F above). Simple removal of leaf tissue may be inconsequential to the ability of moonworts to survive, although removing sporulating individuals may eventually have an effect (Johnson-Groh 1999). Wagner and Wagner (1993) also stated that taking many samples will have little effect on the population as long as the underground shoots and roots are left intact. However, Hoefferle (1999) found that if the aboveground plant was removed after spore release, the trophophore the following year was significantly smaller. Removal before sporulation had no effect. It should be noted that this was a one-year study and weather conditions could have had an impact (Hoefferle 1999). Longer studies have indicated that the removal of leaves had no effect on subsequent leaf size or vigor (Johnson-Groh and Farrar 1996a, b). However, grapeferns may depend more on photosynthesis than moonworts (Johnson-Groh, reported in USDA Forest Service, Eastern Region 1999). It is possible that

since grapeferns are semi-evergreen, nutrients may be recycled from the old frond into the new one, and premature removal or frequent collecting may be detrimental (USDA Forest Service, Eastern Region 1999). Some species of *Botrychium* may also be collected by herbalists due to perceived medicinal powers.

In a French study (Muller 1992), drought-like conditions resulted in wilted *Botrychium* sporophytes before sporulation. The work of Johnson-Groh (1999) also emphasizes the importance of water relations to moonworts and their supporting mycorrhizae. Mycorrhizae are likely the most limiting factor for *Botrychium* establishment, distribution, and abundance (Johnson-Groh 1999); therefore anything that affects mycorrhizae negatively may be expected to also have deleterious effects on *Botrychium*.

Large decreases in mycorrhizal fungi have occurred following earthworm invasion in deciduous hardwood forests (Nielsen and Hole 1963 and 1964, Cothrel et al. 1997, Nixon 1995). A similar effect may occur in the wetter forested habitats often favored by *B. oneidense*. Since most mycorrhizal activity occurs in the interface between the O and A horizons (Read 1994), the concurrent action of exotic earthworms in the same area may have significant effects. The exotic earthworms have their largest impact on the organic surface layer present in some soils (Langmaid 1964). The potential of the threat to *B. oneidense* and its habitat is uncertain, but the wetter areas favored by *B. oneidense* sometimes have a organic surface layer of considerable thickness.

Threat from exotic earthworms

Native earthworms were eliminated from the Lake States during the last ice age. Natural recolonization from the unglaciated south has been extremely slow, with reported distances of less than 100 miles in the centuries since glacial retreat (James 1990, Berlinger 2000, Conover 2000). European earthworms were introduced into North America with European settlement and then spread through the use of earthworms for fishing bait, gardening, and inadvertent human transport (Kalisz and Wood 1995, Berlinger 2000). Logging machinery and other forest vehicles can transport cocoons and hatchlings, thereby dispersing earthworms widely into forests (Marinissen and van den Bosch 1992, Dymond et al. 1997). More remote forests in our region still lack earthworms, but as humans move through the landscape the probability of colonization is increasing (Casson et al. 2000).

Worms have been considered to have a very positive influence on soil structure, litter decomposition, and mineralization and cycling of nutrients (review in Lee 1985), but since regional ecosystems have evolved in the absence of earthworms (James 1990), their recent introduction is having serious consequences.

One of the earliest studies of non-native earthworms in forested habitats documented a disappearance of the organic surface horizon, an increase in the depth and character of the A layer, and a decrease in the B horizon (Langmaid 1964). Another study stated that worms “eliminated the forest floor” (Groffman et al. 2000). Alban and Berry (1994) provided the first detailed documentation of earthworm effects in Minnesota forest soils where they dramatically reduced the litter and duff layers, eliminated the E-layer, and increased the A

horizon. Worms also can make the soil more permeable to water (Peterson and Dixon 1971), potentially altering water relations, especially near the surface.

Leaf litter can be completely broken down in as little as 4 weeks by worms (Knollenberg et al. 1985), in a natural forest system it has been estimated that it might take 3–5 years for decomposition (Mortensen and Mortensen 1998). Earthworms introduced to mine spoil banks have been seen to have dramatic effects on the litter layer, burying or consuming 5 metric tons of leaf letter/ha within 2 years (Vimmerstedd and Finney 1973).

The evidence suggests that the several species of exotic earthworms now colonizing the Lake States region will have considerable impact on native plants including a moonwort species, *B. mormo*. A comparison of 6 plots with earthworms compared to 6 plots without worms (a low sample size) in the Chippewa NF found that 70% of the plant species were adversely affected by worms and 25 species, 50 % of all the species present in the undisturbed plots and including *B. mormo*, were apparently eliminated by the worms (Almendinger 1998). Others have also reported decreased diversity in the herbaceous understory (Nielsen and Hole 1963 and 1964, Nixon 1995, Cothrel et al. 1997). It has been suggested that European earthworms may be incompatible with the survival of many North American hardwood understory species (Hale et al. 1999), although some species have been noticed to increase in numbers after worm invasion (Almendinger 1998, Berlinger 2000).

In an ongoing *B. mormo* monitoring effort on the Chippewa National Forest (Johnson-Groh 1999), plots impacted by worms exhibited significant negative effects on *B. mormo* populations. However, she cautioned that, while the worms likely had fatally affected the plants, all other populations also showed decreases during that dry period. She also observed that it is normal for moonwort populations to fluctuate widely and that population declines may be due to a population exceeding the carrying capacity of a site. Another monitoring study in the same area also observed negative effects on soil properties and a dramatic reduction in the *B. mormo* population following exotic earthworm invasion (Casson et al. 2000). However the habitat favored by *B. mormo* is predominantly rich upland forests, and it is uncertain if exotic earthworms will impact the wetter forests and pond edges that are typical *B. oneidense* habitat in the Great Lakes region.

The loss of the soil organic layer may affect *Botrychium* through their obligate association with mycorrhizal fungi. The fungi may perish with the loss of the forest floor (Nixon 1995) or may also be eaten by sowbugs, which, in at least one instance seem to be invading sites with exotic earthworms (Wolff et al. 1997).

STEWARDSHIP OVERVIEW AND POPULATION VIABILITY CONCERNS

Often it is difficult to determine what factor or combination of factors is impacting *Botrychium* populations (USDA Forest Service, Eastern Region 1999). Populations are inherently variable (Johnson-Groh 1999) but maintaining the health of the mycorrhizae seems to be an underlying necessity. Also critical are moisture relations, as activities that dry

the habitat may have deleterious effects on the population, especially since this species seems to favor damper habitats. Timber harvesting has been recognized as a threat (USDA Forest Service, Eastern Region 1999, USDA Forest Service 2000, NatureServe 2001), but no research has been reported on the response of *B. oneidense* populations to management of any kind. A no-impact buffer surrounding populations is recommended (NatureServe 2001).

RESEARCH AND MONITORING REQUIREMENTS

Like all *Botrychium*, *B. oneidense* is fairly small, inconspicuous, and difficult to find. *Botrychium* may go dormant and not appear aboveground in a given year (Lesica and Ahlenslager 1996). There are almost certainly undiscovered sites for *B. oneidense*, and inventories for the plant should continue. While some research data has been developed about population fluctuations for certain species of moonworts (Johnson-Groh 1999), specific information for grapeferns, and specifically *B. oneidense* population biology, is lacking. Research gaps exist for nearly every aspect of *B. oneidense* ecology; these areas include basic life history information (germination requirements, growth requirements, and life-span), habitat requirements, and management needs (NatureServe 2001).

Almost no information is available on *B. oneidense* life history in relation to disturbance, succession, and colonization of new sites. It is unclear how *B. oneidense* reacts to site changes over time. Monitoring needs include an assessment of population stability, and the tracking of habitat changes through time (NatureServe 2001). Long-term monitoring programs as suggested by Ostlie (1990) and Johnson-Groh (1999) are recommended.

Habitat monitoring is also a need for the species. Correlations between changes in habitat and reproductive success can give strong recommendations toward future management activities. Such monitoring will also indicate the appropriate time to initiate management activities. Basic management information such as percent canopy preference or level of competition tolerated are major needs in order to implement appropriate management programs (NatureServe 2001).

Specific information on *B. oneidense* life history is needed including its important relationship with mycorrhizal fungi and its belowground ecology in general. Data on spore dispersal are also lacking.

Exotic earthworms are a serious threat to some moonwort species, particularly *B. mormo* (Sather et al. 1998). It is unknown if exotic earthworms threaten *B. oneidense* populations or habitats.

Berlin et al. (1998) make a number of specific research and monitoring recommendations for the moonwort, *B. mormo*. Many of their suggestions apply to other *Botrychium* species also; that source should be consulted for detailed recommendations about *Botrychium* monitoring and research. There are also a number of specific suggestions about habitat and population monitoring for *B. rugulosum* that generally apply to most rare *Botrychium* spp. at www.natureserve.org (NatureServe2001).

In small populations, individual counts of the entire group should be made. In large populations, a representative sample of the population should be monitored through a randomized, permanent plot methodology. Individuals within each plot can be mapped as an aid to tracking, possibly providing detailed information pertaining to the species' life span, dormancy, recruitment, etc.

Habitat monitoring should also be considered at selected sites. Perhaps the easiest and most effective way of monitoring habitat would be through permanent photo-points. Although photo-points may not provide the detailed information pertaining to species composition within a given site, rough changes in habitat should be observable. Photo-point analysis of canopy cover, and shrub and ground layer competition with respect to population trends would provide useful information for possible management procedures. Other more time-intensive procedures designed to statistically track changes in composition of the ground-layer associates at each site may be installed and monitored along with the methodology designed to track population trends, as discussed above.

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Natural Heritage Program Databases consulted and queried

UNITED STATES
Michigan: http://www.dnr.state.mi.us/wildlife/heritage/mnfi/
Minnesota: http://www.dnr.state.mn.us/ecological_services/nhnrp/index.html
Wisconsin: http://www.dnr.state.wi.us/org/land/er/nhi/nhi.htm
Illinois: http://dnr.state.il.us/
Indiana: http://www.ai.org/dnr/naturepr/index.htm
Iowa: http://www.state.ia.us/dnr/organiza/ppd/nai.htm
Ohio: http://www.dnr.state.oh.us/odnr/dnap/dnap.html
North Dakota: http://www.abi.org/nhp/us/nd/index.html

CANADA
Ontario: http://www.mnr.gov.on.ca/MNR/nhic/nhic.html
Quebec: http://www.menv.gouv.qc.ca/biodiversite/centre.htm

APPENDICES

APPENDIX A. *Botrychium Oneidense* Element Occurrence Records

The following information was obtained from natural heritage programs in Michigan, Minnesota, Wisconsin, and adjacent states (U.S.) and provinces (Canada). National Forests within the Great Lakes region also provided survey data on species occurrences within each Forest.

Element occurrence summary:
Michigan 2
Minnesota 32
Wisconsin 19

MICHIGAN

Location: Michigan, Delta County
Ownership: Forest Service
Abundance: 12 estimated
Habitat: Wet pocket in jack pine barrens on sandy outwash plain, sandy soils. Associates include *Calamagrostis canadensis, Lycopus, Iris versicolor, B. multifidum, B. rugulosum, Spiraea alba, Gaultheria procumbens, Chamaedaphne calyculata*.
Source of information: Hiawatha National Forest Occurrence Record

Location: Michigan, Alger County
Ownership: Forest Service
Abundance: 12 estimated
Habitat: Northern mesic forest dominated by sugar maple and beech.
Source of information: Hiawatha National Forest Occurrence Record

MINNESOTA

Location: Minnesota, Aitkin County
Ownership: Unknown
Abundance: Not listed
Habitat: Plants occur in a tiny remnant of maple-basswood forest with *Allium tricoccum, Hydrophyllum virginianum, Caulophyllum thalictroides,* and *Botrychium lanceolatum* var. *angustisegmentum, B. matricariifolium,* and both forms of *B. dissectum*.
Comments: 1993
Source of information: Minnesota Natural Heritage Program Element Occurrence Record

Location: Minnesota, Aitkin County
Ownership: Unknown
Abundance: Not listed
Habitat: Just at or above the high water line at the margin of a spring ephemeral pool; at the edges of mossy humps at the high water margin. Mixed hardwood forest dominated *by Tilia*

americana and *Acer saccharum*. Usually saturated in spring, moist other seasons. Infrequent and inconspicuous. Associated with *Ilex verticillata, Carex tuckermanii, Botrychium dissectum,* and *B. multifidum.*
Comments: 1992
Source of information: Minnesota Natural Heritage Program Element Occurrence Record

Location: Minnesota, Aitkin County
Ownership: Unknown
Abundance: Not listed
Habitat: Low wooded site transected by a moist swale, dominated by *Acer saccharum* and *Tilia americana*, moist soil adjacent to wet swale. Margins are more sharply dentate than most oneidense. Associated with *Ilex verticillata, Carex intumescens, Aralia nudicaulis, Aster macrophyllus, Clintonia borealis.*
Comments: 1993
Source of information: Minnesota Natural Heritage Program Element Occurrence Record

Location: Minnesota, Aitkin County
Ownership: State
Abundance: Not listed
Habitat: Narrow strip between road and ash swamp, dominated by *Acer saccharum* and *Tilia americana*.
Comments: 1993
Source of information: Minnesota Natural Heritage Program Element Occurrence Record

Location: Minnesota, Aitkin County
Ownership: State
Abundance: Not listed
Habitat: Gently sloped terrain with numerous small ephemeral pools and washes, dominated by *Acer saccharum* and *Tilia americanum*. Moist areas at pool and wash margins.
Comments: 1993
Source of information: Minnesota Natural Heritage Program Element Occurrence Record

Location: Minnesota, Aitkin County
Ownership: Private
Abundance: Not listed
Habitat: Remnant stand of jack pine dominated by *Pinus resinosa*. Plants growing in sandy, loam. Associated with *Gaultheria procumbens, Chimaphila umbellata*.
Comments: 1991
Source of information: Minnesota Natural Heritage Program Element Occurrence Record

Location: Minnesota, Aitkin County
Ownership: Unknown
Abundance: Not listed
Habitat: On a forested ridge around a small pool in a maple-basswood forest. Several large white cedar and yellow birch in the hardwood mix. Associated with *Aralia nudicaulis, Maianthemum canadense, Trientalis borealis, Botrychium matricariifolium, B. mormo*

Comments: 1996
Source of information: Minnesota Natural Heritage Program Element Occurrence Record

Location: Minnesota, Aitkin County
Ownership: State
Abundance: 3 plants
Habitat: Mature northern hardwood forest dom by *Tilia americana, Acer rubrum, Quercus rubra, Q. Macrocarpa* and *Fraxinus pensyl*. Dark mesic loam in low, level area near edge of wetland. In sparsely vegetated areas including bare soil around tree tip-up mounds. Associated with *Botrychium dissectum, Brachyelytrum erectum, Osmorhiza claytonii, Athyrium filix-femina, Petasites frigidu*s and *Acer saccharum* seedlings.
Comments: 1996
Source of information: Minnesota Natural Heritage Program Element Occurrence Record

Location: Minnesota, Aitkin County
Ownership: Unknown
Abundance: 3 plants
Habitat: Low area in mature maple-basswood forest. Canopy of *Fraxinus nigra, Acer saccharum* and *Tilia americana*. Soil with a thick, moist organic layer over rocky loam. Sparse herbaceous cover here. Associated with *Botrychium matricariifolium, B. lanceolatum, Lycopodium lucidulum, Athyrium filix-femina, Maianthemum canadense*, and *Acer saccharum* seedlings. 3 plants in 1 acre low area with more moisture than surrounding soil.
Comments: 1996
Source of information: Minnesota Natural Heritage Program Element Occurrence Record

Location: Minnesota, Aitkin County
Ownership: Unknown
Abundance: About a dozen plants seen
Habitat: In a small ashy swale in a maple-basswood forest. Associated with *Botrychium dissectum, B. multifidum.*
Comments: 1997
Source of information: Minnesota Natural Heritage Program Element Occurrence Record

Location: Minnesota, Aitkin County
Ownership: Unknown
Abundance: Not listed
Habitat: Near the north shore of a lake. Low lying area in hardwood forest.
Comments: 1997
Source of information: Minnesota Natural Heritage Program Element Occurrence Record

Location: Minnesota, Aitkin County
Ownership: County
Abundance: Not listed
Habitat: Maple-basswood forest with *Betula alleghaniensis, Thelypteris phegopteris, Aralia nudicaulis*. Plants intermixed in a dense localized patch of *Carex pensylvanica*.
Comments: 1997

Source of information: Minnesota Natural Heritage Program Element Occurrence Record

Location: Minnesota, Aitkin County
Ownership: State
Abundance: Several plants observed.
Habitat: At upper edge of small vernal pool with scattered *Fraxinus nigra, Acer saccharum, Tilia americana*. Plants occur on flats above high water margin. Adjacent forest also includes *Ostrya virginiana, Quercus rubra* and *Betula papyrifera.* Associated spp: *Botrychium dissectum* var. *dissectum and* var. *obliquum* and *B. multifidum.*
Comments: 1997
Source of information: Minnesota Natural Heritage Program Element Occurrence Record

Location: Minnesota, Aitkin County
Ownership: State
Abundance: Not listed
Habitat: At edge of small, wet black ash inclusion and maple-basswood forest. Associated spp include *B. multifidum, Athyrium filix-femina* and *Arisaema triphyllum.*
Comments: 1997
Source of information: Minnesota Natural Heritage Program Element Occurrence Record

Location: Minnesota, Aitkin County
Ownership: State
Abundance: Approx a dozen plants
Habitat: Located at seasonal high water line of small vernal pond. Predominantly *Acer saccharum, Tilia americana, Quercus rubra* forest. Pond has a few *Fraxinus pensylvanica, Rubus pubescens* and *B. multifidum.*
Comments: 1997
Source of information: Minnesota Natural Heritage Program Element Occurrence Record

Location: Minnesota, Aitkin County
Ownership: Unknown
Abundance: Rare
Habitat: Oak/northern hardwood forest dominated locally by *Acer rubrum, Populus tremuloides* and *Fraxinus pensylvanica*. Compacted, rocky, silt-loam. Sparsely vegetated, slight depression/ephemeral pool under canopy. Associates include *Botrychium multifidum, Onoclea sensibilis, Carex arctata, C. pensylvanica*. Nearly level terrain.
Comments: 1996
Source of information: Minnesota Natural Heritage Program Element Occurrence Record

Location: Minnesota, Aitkin County
Ownership: State
Abundance: Not listed
Habitat: Growing in an older patch of northern hardwood forest (estimated 40-60 vs 10-40 years old) with *Acer saccharum* rather than *Populus*-dominated canopy. In shallow 1-3 sq m depression on a deer trail with *Athyrium filix-femina, Clintonia borealis, Maianthemum canadense,* and *Aralia nudicaulis*

Comments: 1998
Source of information: Minnesota Natural Heritage Program Element Occurrence Record

Location: Minnesota, Carlton County
Ownership: State
Abundance: Occasional.
Habitat: Growing in a flat, meadow-woodland dominated by scattered clumps of *Corylus cornuta* and herbaceous species (*Calamagrostis canadensis, Carex leptonervia, Aster umbellatus, Cornus canadensis, Pteridium aquilinum*) with scattered young *Acer rubrum* and *Fraxinus nigra*.
Comments: 1996
Source of information: Minnesota Natural Heritage Program Element Occurrence Record

Location: Minnesota, Cass County
Ownership: Private
Abundance: Abundant (many 100s variously-sized plants with fertile fronds)
Habitat: in shallow depressions between small rises in gently undulating landscape. Plants occur in second-growth forest of *Fraxinus nigra, Populus tremuloides, Acer saccharum* and *Quercus rubra*. *Botrychium rugulosum* also present.
Comments: 1992
Source of information: Minnesota Natural Heritage Program Element Occurrence Record

Location: Minnesota, Itasca County
Ownership: USFS
Abundance: 2 plants
Habitat: Plants occur in a moist ephemeral pool in a deciduous forest dominated by *Acer saccharum* and *Tilia americana*. Two plants observed with *Botrychium multifidum*.
Comments: 1994
Source of information: Minnesota Natural Heritage Program Element Occurrence Record

Location: Minnesota, Mille lacs County
Ownership: Unknown
Abundance: Not listed
Habitat: In low maple-basswood forest adjoining the cedar creek wetland.
Comments: 1993
Source of information: Minnesota Natural Heritage Program Element Occurrence Record

Location: Minnesota, Pine County
Ownership: Private
Abundance: Not listed
Habitat: Plants occur along the edge of a low area in a deciduous forest dominated by *Acer saccharum* and *Quercus rubra*. *Botrychium multifidum* and *B. virginianum* also occur on this undulating plateau above the terraces of the St. Croix River.
Comments: 1993
Source of information: Minnesota Natural Heritage Program Element Occurrence Record

Location: Minnesota, Pine County
Ownership: State
Abundance: 4 plants
Habitat: Mature/old growth northern hardwood forest. Canopy dom by *Acer saccharum, A rubrum, Quercus rubra, Tilia americana* with occasional *Fraxinus nigra, Betula alleghaniensis* and *Thuja occidentalis*. Moist to mesic organic soil. Level ground moraine 50m from edge of black ash swamp. Associated with *Botrychium dissectum, B. matricariifolium, B. lanceolatum, Carex arctata, C. brunnescens, C. pedunculata, Uvularia sessilifolium, Athyrium filix-femina.*
Comments: 1995
Source of information: Minnesota Natural Heritage Program Element Occurrence Record

Location: Minnesota, Pine County
Ownership: State
Abundance: Not listed
Habitat: Low ridge by river between the river and a lower floodplain, dominated by *Acer saccharinum*. Sandy silty alluvia. Associated with *Carex, Botrychium dissectum.*
Comments: 1993
Source of information: Minnesota Natural Heritage Program Element Occurrence Record

Location: Minnesota, Pine County
Ownership: Unknown
Abundance: Not listed
Habitat: Plants occur in a deciduous forest dominated by *Acer saccharum* and *Quercus rubra*. Associated with *Acer rubrum, Athyrium filix-femina, Lycopus uniflorus, Scutellaria galericulata, Nemopanthus mucronatus*. Growing in a moist area at the base of a gentle slope.
Comments: 1993
Source of information: Minnesota Natural Heritage Program Element Occurrence Record

Location: Minnesota, Pine County
Ownership: Unknown
Abundance: Not listed
Habitat: Plants growing in a deciduous forest dominated by *Acer saccharum* and *Tilia americana*. Associated with *Botrychium lanceolatum* var. *angustisegmentum, B. matricariifolium, B. dissectum, Allium tricoccum, Mitella diphylla*.
Comments: 1993
Source of information: Minnesota Natural Heritage Program Element Occurrence Record

Location: Minnesota, Pine County
Ownership: State
Abundance: 8 plants seen in 35 acre stand
Habitat: Northern hardwood forest on small upland island surrounded by ash swamp. Low ecotonal area between upland and swamp. Canopy of mature *Acer saccharum, A. rubrum, Fraxinus nigra* and *Betula alleghaniensis*. Associated with *Brachyelytrum erectum,*

Lycopodium lucidulum, Athyrium filix-femina, Maianthemum canadense, Equisetum sylvaticum, Acer spicatum, and *Acer saccharum* seedlings
Comments: 1996
Source of information: Minnesota Natural Heritage Program Element Occurrence Record

Location: Minnesota, Pine County
Ownership: State
Abundance: Not listed
Habitat: Plants growing along the se-facing sandstone escarpment of a river. Associated species include: *Viola novae-angliae, Lonicera canadensis, Carex media, Dryopteris fragrans* and *Primula mistassininca*.
Comments: 1993
Source of information: Minnesota Natural Heritage Program Element Occurrence Record

Location: Minnesota, Washington County
Ownership: State
Abundance: Few plants
Habitat: River bottom forest dominated by *Pinus strobus* and *Acer saccharinum*. Only a few plants seen growing with many *Botrychium dissectum, Ilex verticillata, Onoclea sensibilis, Aster*.
Comments: 1995
Source of information: Minnesota Natural Heritage Program Element Occurrence Record

Location: Minnesota, Washington County
Ownership: State
Abundance: Not listed
Habitat: Boxelder grove with an understory of overmature plum in a moist mossy swale. Associated with *Eupatorium rugosum, Parthenocissus inserta, Rubus strigosus, Liparis liliifolia*.
Comments: 1997
Source of information: Minnesota Natural Heritage Program Element Occurrence Record

Location: Minnesota, Winona County
Ownership: City
Abundance: Few plants
Habitat: Floodplain forest dominated by *Acer saccharinum* and *Betula nigra*. Only a few plants scattered among hundreds of *B. dissectum*. Associated with *Rhus radicans, Lysimachia nummularia.*
Comments: 1997
Source of information: Minnesota Natural Heritage Program Element Occurrence Record

Location: Minnesota, Winona County
Ownership: State
Abundance: Not listed
Habitat: Located at border/edge of wetland surrounded by *Fraxinus nigra* with *Botrychium dissectum* var. *dissectum.*

Comments: 1999
Source of information: Minnesota Natural Heritage Program Element Occurrence Record

WISCONSIN

Location: Wisconsin, Brown County
Ownership: Not listed
Abundance: 1980: Species collected
Habitat: Maple woods with moist depressions .
Source of information: Wisconsin Natural Heritage Program Element Occurrence Record

Location: Wisconsin, Waupaca County
Ownership: Not listed
Abundance: 1978: Species collected
Habitat: Woods with *Tilia, Carpinus,* and red maple.
Source of information: Wisconsin Natural Heritage Program Element Occurrence Record

Location: Wisconsin, Wood County
Ownership: Not listed
Abundance: Specimens collected in 1915.
Habitat: Damp, open woods.
Source of information: Wisconsin Natural Heritage Program Element Occurrence Record

Location: Wisconsin, Forest County
Ownership: Not listed
Abundance: 1979: Sterile plant collected.
Habitat: Low, moist second-growth woods.
Source of information: Wisconsin Natural Heritage Program Element Occurrence Record

Location: Wisconsin, Taylor County
Ownership: Forest Service
Abundance: 1979: Species collected.
Habitat: Maple-basswood woods.
Source of information: Wisconsin Natural Heritage Program Element Occurrence Record

Location: Wisconsin, Price County
Ownership: Not listed
Abundance: 1979: Species collected.
Habitat: Maple-basswood woods.
Source of information: Wisconsin Natural Heritage Program Element Occurrence Record

Location: Wisconsin, Rusk County
Ownership: Not listed
Abundance: 1979: Species collected.
Habitat: Bog edge at maple-basswood forest.
Source of information: Wisconsin Natural Heritage Program Element Occurrence Record

Location: Wisconsin, Ashland County
Ownership: Forest Service
Abundance: 1980: Species collected
Source of information: Wisconsin Natural Heritage Program Element Occurrence Record

Location: Wisconsin, Sawyer County
Ownership: No listed
Abundance: 1979: Species observed.
Habitat: Poorly-drained outwash topography. Large undeveloped swampy wetland with second-growth sugar maple on the uplands.
Source of information: Wisconsin Natural Heritage Program Element Occurrence Record

Location: Wisconsin, Taylor County
Ownership: Forest Service
Abundance: 1994: About 10 stems, 90% in flower/bud, 10 % mature but non-flowering
Habitat: Plants in full shade, SSE aspect in moist rich soil. Northern hardwoods; sugar maple with basswood. Rich understory, many fern species. Also present is *B. lanceolatum* var. *angustisegmentum, B. matricariifolium, B. virginianum.*
Comments: Proposed timber sale.
Source of information: Wisconsin Natural Heritage Program Element Occurrence Record

Location: Wisconsin, Forest County
Ownership: Private
Abundance: 1994: Species observed, "not common."
Habitat: Relatively mature mesic forest with full canopy dominated by *Acer saccharum*. Understory of typical mesic forest spring ephemerals including *Trillium grandiflorum, Dicentra cucullaria*, *Claytonia caroliniana,* etc. Rich leaf mold spoil.
Comments: 2 listings with this information.
Source of information: Wisconsin Natural Heritage Program Element Occurrence Record

Location: Wisconsin, Forest County
Ownership: County
Abundance: 1994: Species observed, "not common"
Habitat: Relatively mature mesic forest with full canopy dominated by *Acer saccharum*. Understory of typical mesic forest spring ephemerals including *Trillium grandiflorum, Dicentra cucullaria*, *Claytonia caroliniana,* etc. Rich leaf mold spoil.
Source of information: Wisconsin Natural Heritage Program Element Occurrence Record

Location: Wisconsin, Oconto County
Ownership: Forest Service
Abundance: 1997: About 6 plants observed, 75% seedling, 25% fertile
Habitat: Edge of old woods road, road surface is same as surrounding soils, partially revegetated with herbaceous plants. Generally closed canopy over roadway. N. mesic forest, rich hardwoods under sugar maple, basswood, beech, occasionally paper birch. Other associated with *B. dissectum*.

Comments: Road received occasional vehicle traffic.
Source of information: Wisconsin Natural Heritage Program Element Occurrence Record

Location: Wisconsin, Ashland County
Ownership: Forest Service, private
Abundance: 1997: Species observed.
Source of information: Wisconsin Natural Heritage Program Element Occurrence Record

Location: Wisconsin, Ashland County
Ownership: Forest Service
Abundance: 1998: 1 plant
Habitat: N. mesic forest dominated by sugar maple and basswood with *Aralia nudicaulis, A. racemosa, Streptopus roseus, B. virginianum, B. matricariifolium, B. lanceolatum, Hepatica acutiloba, Maianthemum canadense, Oryzopsis asperifolia, Uvularia grandiflora,* and *Sanguinaria canadensis*.
Source of information: Wisconsin Natural Heritage Program Element Occurrence Record

Location: Wisconsin, Forest County
Ownership: Forest Service
Abundance: 2000: 1 plant
Habitat: Sugar maple dominated forest, scattered beech, basswood. In thick leaf litter, closely associated with *Carex pensylvanica*. Canopy nearly closed but somewhat thin so plants receive a moderate amount of light. With *Polygonatum pubescens, Maianthemum, Adiantum, Viola* spp., *Hydrophyllum virginianum*.
Source of information: Wisconsin Natural Heritage Program Element Occurrence Record

Location: Wisconsin, Forest County
Ownership: Forest Service
Abundance: 2000: 1 plant
Habitat: Sugar maple dominated forest, scattered beech, basswood. In thick leaf litter and duff. Canopy closed, in complete shade. Under multi-stemmed basswoods. *B. mormo* also present.
Source of information: Wisconsin Natural Heritage Program Element Occurrence Record

Location: Wisconsin, Price County
Ownership: Forest Service
Abundance: 2000: 6 plants, basal rosettes of this years and last years leaves
Habitat: Mesic sugar maple, basswood, white ash forest. In full shade, on dried edge of ephemeral pond, sandy loam soil, level to slightly rolling topography. With *Viola pubescens, Asarum canadense.*
Source of information: Wisconsin Natural Heritage Program Element Occurrence Record

APPENDIX B. *Botrychium* Status And Threats Summary

Three tables are presented below. Table 1 summarizes the state, national, and global status of each *Botrychium* taxon. Table 2 summarizes range, population, and habitat features. Table 3 ranks the degree of threat to populations of each taxon from various factors. The assigned rankings are intended as general guidelines based on information presented in each conservation assessment. For many taxa, detailed ecological information is lacking.

Table 1. *Botrychium* status.

	Status			
	Minnesota	**Michigan**	**Wisconsin**	**Global/National**
B. campestre	SC (S3)	T (S2)	E (S1)	G3/N3
B. dissectum	(not listed) SU	(not listed) S?	(not listed) SR	G5/N5
B. hesperium (B. michiganense)	(not listed)	T (S1S2)	(absent)	G3/N2
B. lanceolatum var.angustisegmentum	T (SR)	(not listed) S4	(not listed) S3	G5/N4
B. lunaria	T (S2)	(not listed) S?	E (S1)	G5/N4?
B. minganense	SC (S3)	(not listed) S?	SC (S2)	G4/N?
B. mormo	SC (S3)	T (S1S2)	E (S2)	G3/N3
B. oneidense	E (S1)	(not listed) S?	SC (S2)	G4Q/N4
B. pallidum	E (S1)	SC (S3)	(absent)	G2G3/N2N3
B. pseudopinnatum	(not listed) S?	(absent)	(not listed)	G1/N1
B. rugulosum	T (S2)	(not listed) S3	SC (S2)	G3/N3
B. simplex	SC (S3)	(not listed) S?	(not listed) S?	G5/N5
B. spathulatum	(not listed) S?	(not listed) S3	SC (S1)	G3/N3

Key
Status:
E = state endangered
T = state threatened
SC = state special concern
S1 = state rankings (see Appendix B)
absent = taxon not known from state
not listed = taxon not tracked by state natural heritage program.
Global/National – worldwide or United States ranking provided by NatureServe (2001, see Appendix B. for definitions).

Table 2. *Botrychium* range, population, and habitat features.

Taxon	Range	Habitat Amplitude	Pop Trend	Habitat Integrity	Vulnerability
B. campestre	wide, disjunct	intermediate	unknown	fair	medium
B. dissectum	wide	broad	increasing	fair	low
B. hesperium (B. michiganense)	endemic	intermediate	stable	fair	medium
B. lanceolatum var. *angustisegmentum*	wide	intermediate	increasing	fair	low
B. lunaria	wide	broad	stable	fair	medium
B. minganense	wide	broad	increasing	good	low
B. mormo	endemic	narrow	decreasing	fair	high
B. oneidense	wide	intermediate	unknown	fair	medium
B. pallidum	narrow	broad	stable	fair	low
B.pseudopinnatum	endemic	narrow	unknown	poor	high
B. rugulosum	narrow	intermediate	stable	fair	low
B. simplex	wide	broad	increasing	good	low
B. spathulatum	narrow	intermediate	unknown	fair	medium

Key

range: wide (occurs across much of North America), narrow (e.g. Lake States), endemic (restricted to Lake States), disjunct (separated from main population).

amplitude: broad (tolerates a variety of habitats and conditions), intermediate, narrow (very specific requirements).

estimated population trend: increasing, stable, decreasing, unknown (insufficient information to estimate trend).

habitat integrity: good (most habitats/sites protected, not commonly impacted by management), fair, poor (most sites degraded, unoccupied habitat subject to numerous impacts), unknown.

vulnerability: high (populations generally not resilient or are intolerant of habitat changes), medium, low (populations resilient and/or resistant to change), unknown.

Table 3. Major threats to *Botrychium*.

	Threat					
	Exotic Earthworms	**Exotic Plants**	**Canopy Thinning**	**Succession To Closed Canopy**	**Disturbance**	
					Major	**Minor**
B. campestre	low	medium	low	high	medium	low
B. dissectum	medium	medium	medium	low	high	medium
B. hesperium (B. michiganense)	medium (forested sites) low (other sites)	medium-high	low	low-medium	medium	low
B. lanceolatum var. *angustisegmentum*	high	medium	medium	low	medium	low
B. lunaria	low	medium	low	medium	medium	low
B. minganense	high	medium	medium	low	medium	medium
B. mormo	high	low	high	low	high	medium
B. oneidense	high	medium	medium-high	low	high	medium-high
B. pallidum	low	high	low	high	medium	low
B.pseudopinnatum	low	high	low	high	medium	low
B. rugulosum	low	medium	low	high	high	medium
B. simplex	medium	medium	low	medium	medium	low
B. spathulatum	low	high	low	high	medium	low

Key
High, medium, or low are used to indicate the estimated degree of impact of a specific threat to a *Botrychium* population.

APPENDIX C. Global, National, And Subnational Conservation Status Ranks (From NATURESERVE, www.natureserve.org).

NatureServe reports the relative imperilment, or conservation status, of plants, animals, and ecological communities (elements) on a global, national, and subnational (state/provincial) level. Based on the conservation status ranking system developed by The Nature Conservancy and the Natural Heritage Network, conservation status ranks are assigned, reviewed, and revised according to standard criteria. Assessing the conservation status of species and ecological communities is the cornerstone of Natural Heritage work. It allows Natural Heritage programs and their cooperators to target the most at-risk elements for inventory, protection, management, and research.

Global, National, and Subnational Conservation Status Ranks

An element is assigned one global rank (called a G-rank), which applies across its entire range; a national rank (N-rank) for each nation in its range; and a subnational rank (S-rank) for each state, province, or other subnational jurisdiction in its range (e.g. Yukon Territory). In general, Association for Biodiversity Information (ABI) scientists assign global, U.S., and Canadian national ranks. ABI scientists receive guidance from subnational data centers, especially for endemic elements, and from experts on particular taxonomic groups. Local data centers assign subnational ranks for elements in their respective jurisdictions and contribute information for national and global ranks. New information provided by field surveys, monitoring activities, consultation, and literature review, improves accuracy and keeps ranks current. Including an annual data exchange with local data centers, ABI's central databases are updated continually with revisions, corrections, and information on ranked elements.

What the Ranks Mean

The conservation rank of an element known or assumed to exist within a jurisdiction is designated by a whole number from 1 to 5, preceded by a G (Global), N (National), or S (Subnational) as appropriate. The numbers have the following meaning:
1 = critically imperiled
2 = imperiled
3 = vulnerable to extirpation or extinction
4 = apparently secure
5 = demonstrably widespread, abundant, and secure.

G1, for example, indicates critical imperilment on a range-wide basis—that is, a great risk of extinction. S1 indicates critical imperilment within a particular state, province, or other subnational jurisdiction, in other words, a great risk of extirpation of the element from that subnation, regardless of its status elsewhere.

Species known in an area only from historical records are ranked as either H (possibly extirpated/possibly extinct) or X (presumed extirpated/presumed extinct). Other codes, rank

variants, and qualifiers are also allowed in order to add information about the element or indicate uncertainty. See the lists of conservation status rank definitions for complete descriptions of ranks and qualifiers.

Rank Definitions

Elements that are imperiled or vulnerable everywhere they occur will have a global rank of G1, G2, or G3 and equally high or higher national and subnational ranks. (The lower the number, the "higher" the rank is in conservation priority.) On the other hand, it is possible for an element to be more vulnerable in a given nation or subnation than it is range-wide. In that case, it might be ranked N1, N2, or N3, or S1, S2, or S3 even though its global rank is G4 or G5. The three levels of the ranking system give a more complete picture of the conservation status of a species or community than either a range-wide or local rank by itself. They also make it easier to set appropriate conservation priorities in different places and at different geographic levels.

In an effort to balance global and local conservation concerns, global as well as national and subnational (provincial or state) ranks are used to select the elements which should receive priority for research and conservation in a jurisdiction. Highest priority should be given to elements that are most vulnerable to extinction—that is, those ranked G1, G2, or G3. And, according to the rules of ranking, these must have equally high or higher national and subnational ranks. Elements vulnerable to national or subnational extirpation (ranks N1, N2, N3, or S1, S2, S3) with global ranks of G4 or G5 should be considered next.

Assessment Criteria

Use of standard ranking criteria and definitions makes Natural Heritage ranks comparable across element groups—thus G1 has the same basic meaning whether applied to a salamander, a moss, or a forest community. Standardization also makes ranks comparable across jurisdictions, which in turn allows ABI scientists to use the national and subnational ranks assigned by local data centers to determine and refine or reaffirm global ranks.

Ranking is a qualitative process: it takes into account several factors, which function as guidelines rather than arithmetic rules. The ranker's overall knowledge of the element allows him or her to weigh each factor in relation to the others and to consider all pertinent information for a particular element. The factors considered in ranking species and communities are similar, but the relative weight given to the factors differs.

For species elements, the following factors are considered in assigning a rank:

- total number and condition of occurrences
- population size
- range extent and area of occupancy
- short- and long-term trends in the foregoing factors
- threats
- fragility

Secondary factors include the geographic range over which the element occurs, threats to occurrences, and viability of the occurrences. However, it is often necessary to establish preliminary ranks for communities when information on these factors is not complete. This is particularly true for communities that have not been well described. In practice, a preliminary assessment of a community's range-wide global rank is often based on the following:
geographic range over which the element occurs
long-term trend of the element across this range
short-term trend (i.e., threats)
degree of site/environmental specificity exhibited by the element
rarity across the range as indicated by subnational ranks assigned by Heritage data centers.

Global Heritage Status Rank Definitions

Rank	**Definition**
GX	Presumed Extinct—Believed to be extinct throughout its range. Not located despite intensive searches of historical sites and other appropriate habitat, and virtually no likelihood that it will be rediscovered.
GH	Possibly Extinct (species)—Known from only historical occurrences, but may nevertheless still be extant; further searching needed.
G1	Critically Imperiled—Critically imperiled globally because of extreme rarity or because of some factor(s) making it especially vulnerable to extinction. Typically 5 or fewer occurrences or very few remaining individuals (<1,000).
G2	Imperiled—Imperiled globally because of rarity or because of some factor(s) making it very vulnerable to extinction or elimination. Typically 6 to 20 occurrences or few remaining individuals (1,000 to 3,000).
G3	Vulnerable—Vulnerable globally either because very rare and local throughout its range, found only in a restricted range (even if abundant at some locations), or because of other factors making it vulnerable to extinction or elimination. Typically 21 to 100 occurrences or between 3,000 and 10,000 individuals.
G4	Apparently Secure—Uncommon but not rare (although it may be rare in parts of its range, particularly on the periphery), and usually widespread. Apparently not vulnerable in most of its range, but possibly cause for long-term concern. Typically more than 100 occurrences and more than 10,000 individuals.

G5 Secure—Common, widespread, and abundant (although it may be rare in parts of its range, particularly on the periphery). Not vulnerable in most of its range. Typically with considerably more than 100 occurrences and more than 10,000 individuals.

National (N) and Subnational* (S) Heritage Status Rank Definitions
* Subnational indicates jurisdictions at the state or provincial level (e.g. California, Ontario).

Rank	Definition
NX **SX**	Presumed Extirpated—Element is believed to be extirpated from the nation or subnation*. Not located despite intensive searches of historical sites and other appropriate habitat, and virtually no likelihood that it will be rediscovered.
NH **SH**	Possibly Extirpated (Historical)—Element occurred historically in the nation or subnation*, and there is some expectation that it may be rediscovered. Its presence may not have been verified in the past 20 years. An element would become NH or SH without such a 20-year delay if the only known occurrences in a nation or subnation were destroyed or if it had been extensively and unsuccessfully looked for. Upon verification of an extant occurrence, NH or SH-ranked elements would typically receive an N1 or S1 rank. The NH or SH rank should be reserved for elements for which some effort has been made to relocate occurrences, rather than simply using this rank for all elements not known from verified extant occurrences.
N1 **S1**	Critically Imperiled—Critically imperiled in the nation or subnation* because of extreme rarity or because of some factor(s) making it especially vulnerable to extirpation from the subnation. Typically 5 or fewer occurrences or very few remaining individuals (<1,000).
N2 **S2**	Imperiled—Imperiled in the nation or subnation* because of rarity or because of some factor(s) making it very vulnerable to extirpation from the nation or subnation. Typically 6 to 20 occurrences or few remaining individuals (1,000 to 3,000).
N3 **S3**	Vulnerable—Vulnerable in the nation or subnation* either because rare and uncommon, or found only in a restricted range (even if abundant at some locations), or because of other factors making it vulnerable to extirpation. Typically 21 to 100 occurrences or between 3,000 and 10,000 individuals.
N4 **S4**	Apparently Secure—Uncommon but not rare, and usually widespread in the nation or subnation*. Possible cause of long-term concern. Usually more than 100 occurrences and more than 10,000 individuals.

N5
S5 Secure—Common, widespread, and abundant in the nation or subnation*. Essentially ineradicable under present conditions. Typically with considerably more than 100 occurrences and more than 10,000 individuals.

N?
S? Unranked—Nation or subnation* rank not yet assessed.

APPENDIX D. Contractor Qualifications And Experience

The conservation assessment was prepared by Steve W. Chadde and Dr. Greg Kudray. Mr. Chadde holds an M.S. degree in Plant Ecology from Montana State University and a B.S. degree in Agriculture from the University of Wyoming. He has conducted numerous botanical and ecological surveys and research studies in both the Great Lakes (Michigan, Minnesota, Wisconsin) and Rocky Mountain regions. Mr. Chadde's primary areas of expertise are endangered, threatened, and sensitive plant surveys, plant community characterization studies, natural areas evaluations, and wetlands inventory, delineation, and mapping. Dr. Kudray holds a Ph.D. in Wetland Ecology from Michigan Technological University. He has extensive experience in ecosystem characterization and mapping, vegetation inventory and monitoring, and forest analysis. Additional information for each author is provided below.

Contact Information

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Internet: www.ecologyusa.com
E-mail: greg@ecologyusa.com
Statement of Qualifications – Steve W. Chadde

Recent Experience

Consulting Botanist
Ottawa National Forest, Lake Superior Land Co., Central Lake Superior Watershed Partnership, U.P. Engineers and Architects, Michigan (partial list only).
Conducted field surveys for endangered, threatened, and rare plant species, and various wetland and other ecological studies.

Botanist, USDA Forest Service
Ottawa National Forest and Hiawatha National Forest, Michigan
Conducted field surveys for endangered, threatened, and rare plant species on national forest lands in Michigan's Upper Peninsula.

Biologist, US Geological Survey
Great Lakes Science Center, Ann Arbor, Michigan
Vegetation scientist for a large wetland restoration project at Seney National Wildlife Refuge in Michigan's Upper Peninsula.

Natural Areas Ecologist, USDA Forest Service/The Nature Conservancy
Northern Region USDA Forest Service, Missoula, Montana
Responsible for identifying and establishing research natural areas (RNAs) and botanical areas on national forests in northern Idaho, Montana, and North and South Dakota. Performed field surveys and baseline inventories of wetlands and natural areas. Conducted field surveys for rare plants and plant communities.

Education

Michigan Technological University—Coursework in the Scientific and Technical Communication program.
M.S. Range Ecology— Montana State University, 1985
B.S. Agriculture (Honors)—University of Wyoming, 1983

Publications

Chadde, Steve. 2000. Natural Features Survey, Lake Superior Shoreline, Marquette County, Michigan. Contract report prepared for Central Lake Superior Watershed Partnership, Marquette.
Chadde, Steve. 1999. A Forester's Field Guide to the Endangered and Threatened Plants of Michigan's Upper Peninsula. Contract report prepared for Mead Corporation, Champion International Corporation, and Shelter Bay Forests.
Chadde, Steve. 1998. A Great Lakes Wetland Flora - A Complete, Illustrated Guide to the Aquatic and Wetland Plants of the Upper Midwest. PocketFlora Press, Calumet, MI. 584 p.
Chadde, Steve, and others. 1998. Peatlands on National Forests of the Northern Rocky Mountains: Ecology and Conservation. USDA Forest Service, Rocky Mountain Research Station General Technical Report RMRS-GTR-11. Ogden, UT.
Chadde, Steve. 1996. Plants of the Copper Country - An Illustrated Guide to the Vascular Plants of Houghton and Keweenaw Counties, Michigan, and Isle Royale National Park. PocketFlora Press, Calumet, MI. 112 p.
Chadde, Steve. 1996. Plants of Pictured Rocks National Lakeshore – A Complete, Illustrated Guide to the Plant's of America's First National Lakeshore. PocketFlora Press, Calumet, MI. 103 p.
Chadde, Steve. 1995. Ecological Evaluation - Findlayson Property, Chippewa County, Michigan. Contract report prepared for Michigan Chapter, The Nature Conservancy.
Chadde, Steve. 1995. Research Natural Areas of the Northern Region: Status and Needs Assessment. USDA Forest Service, Northern Region, Missoula, MT. 164 p.
Rabe, Fred, and Steve Chadde. 1995. Aquatic Features of Research Natural Areas of the Kootenai and Flathead National Forests, Montana. USDA Forest Service, Northern Region, Missoula, MT. 66 p. plus appendices.

Rabe, Fred, and Steve Chadde. 1994. Classification of Aquatic and Semiaquatic Wetland Natural Areas in Idaho and Western Montana. Natural Areas Journal 14(3): 175-187.
Statement of Qualifications – Dr. Greg Kudray

Recent Experience

Ecological Inventory and Analysis, Chassell, MI. Established company in June 1999 to conduct ecological consulting work for individuals, corporations, and government agencies. Contracted with the Hiawatha National Forest to do ecosystem mapping, the correlation of ecosystem types to soil types, and the training of Hiawatha personnel in ecosystem inventory and mapping. Contracted with the USGS to do wetland vegetation monitoring in the Seney National Wildlife Refuge. Other experience includes teaching wetland plant workshops, evaluation and mapping of exotic plant infestions, vegetation inventory, bryophyte identification, and aquatic plant monitoring. Six seasonal employees in 1999.

Michigan Technological University, Department of Forestry and Wood Products, Houghton, MI. Employed as a research scientist with primary responsibilities involving ecosystem classification and mapping with related database management and data analysis for the Hiawatha National Forest. Wetland mapping was based on a key and field guide developed during my doctoral research and continually refined through multivariate data analysis. In this position I trained and supervised a seasonal crew of biologists (8 in 1996, 9 in 1995, 3 in 1994) to conduct field mapping integrating vegetation, soil, and hydrological data. I also trained and coordinated four employees from the USDA Natural Resources Conservation Service (former USDA Soil Conservation Service) during the 1995 season and USDA Forest Service personnel throughout the project. Accomplishments include the fine-scale mapping of approximately 300,000 acres in the western half of the Hiawatha National Forest and the development of a database with detailed soil characterizations, hydrological data, and vascular and bryophyte plant information from 4000 plot records. In addition to this work I was an instructor in the 1994 Wetland Ecology course (FW 451), taught a 2 day Clear Lake Conference wetlands plant workshop, and also taught the wetland ecology section during a USFS silvicultural certification workshop offered by our department. (1994 to Nov. 1996)

Michigan Department of Natural Resources, Forest Management Division, Baraga Field Office. Assistant area forester supervising two forest technicians. Primarily responsible for the operations inventory and timber sale programs on the 135,000 acre Baraga area state forest. Conducted and supervised stand exam, type mapping, timber volume estimates, stumpage appraisal, and timber sale contract compliance. Other duties included Commercial Forest Act administration, insect surveys, wildfire suppression, road layout, and forest regeneration activities. Overall performance appraisal rating term for 1989 was "exceptional". Received 1989 DNR District One award for overall excellence. (1984 to 1990)

EDUCATION

Michigan Technological University, Houghton, Michigan. Ph.D. in Wetland Ecology. 1999. Research project involved the development of a ecosystem classification system for the wetlands of the Hiawatha National Forest. Attended University of Michigan Biological Station 1991 summer session with classes in Bryology and Aquatic Plants. Other areas of specialization include soil science, hydrology, forest and landscape ecology, vegetation science, statistics, and remote sensing/GIS applications in land management. Overall GPA of 4.0. (1990 to 1994, Nov. 1996 to June 1999). Published book chapter on the relationship of peatland types and vegetation to water chemistry, other publications in review.

Michigan State University, East Lansing, Michigan. MS specializing in Forest Genetics. 1979. Masters thesis was an evaluation of a spruce hybrid breeding program. Work as a research assistant included controlled pollinations, greenhouse propagation, and plantation establishment. Initiated a computerized record keeping system for a breeding arboretum. Published scientific article based on my research. Overall GPA of 3.6. (1977 to 1979)

Michigan State University, East Lansing, Michigan. BS in Forestry. 1976.
Graduated with high honor including Honors College membership. Also a member of Alpha Zeta, Beta Beta Beta, and Phi Kappa Phi honorary societies. Overall GPA of 3.8. (1972 to 1976)