Conservation Assessment

For

Narrow Triangle Moonwort (Botrychium lanceolatum var. angustisegmentum)

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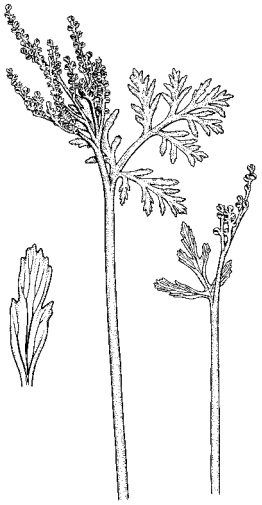

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USDA Forest Service, Eastern Region

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This Conservation Assessment was prepared to compile the published and unpublished information on the subject species or community. 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 taxon, please contact the Eastern Region of the Forest Service Threatened and Endangered Species Program at 310 Wisconsin Avenue, Milwaukee, Wisconsin 53203.

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EXECUTIVE SUMMARY

Botrychium lanceolatum var. *angustisegmentum* (narrow triangle moonwort) is a small fern that ranges across much of the northeastern United States and Canada. It is extremely rare in Minnesota, not uncommon in Wisconsin and Michigan, and especially common on the Ottawa National Forest in Michigan's western Upper Peninsula. Its habitat is somewhat variable, occurring mostly in northern hardwood forests in our region, but also in other kinds of forests and sometimes in openings. The greatest threat to the species is generally considered disruption of its habitat from logging. However, plants occur in second-growth and tertiary forests, and no management-related research has been conducted specifically on timber-harvest impacts. Details about the biology of *B. lanceolatum* var. *angustisegmentum* are generalized from studies of other *Botrychium* species. Much of the life-cycle occurs underground, populations of aboveground sporophytes probably fluctuate and individual plants may not appear every year, complicating attempts to adequately inventory the population. Like other moonworts, *B. lanceolatum* var. *angustisegmentum* is dependent on a mycorrhizal relationship; thus any concerns about species conservation must include consideration of this relationship. No information is available on managing habitat to maintain the species. Since the species is small and populations fluctuate, continued inventory efforts are necessary to better refine population demographics, range, and habitat. Much basic research on *B. lanceolatum* var. *angustisegmentum* 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:

-Provide an overview of current scientific knowledge for *B. lanceolatum* var. *angustisegmentum*.
-Provide a summary of the distribution and status of *B. lanceolatum* var. *angustisegmentum*, both rangewide and within the Eastern Region of the USDA Forest Service.
-Provide the available background information needed to prepare a subsequent Conservation Strategy.

In North America, the genus *Botrychium*, family Ophioglossaceae, is comprised of three subgenera (Lellinger 1985, Wagner and Wagner 1993). One subgenus, *Osmundopteris*, is represented in our area only by *B. virginianum*, the rattlesnake fern, which is common around much of the world (Wagner 1998). Subgenus *Sceptridium*, the grapeferns, encompasses plants which are are medium-sized and decidedly evergreen (Lellinger 1985). Subgenus *Botrychium*, the moonworts, which includes *B. lanceolatum* var. *angustisegmentum*, are

numerous species of often rare, local and very small plants that are difficult to find and positively identify. North America is a center of diversity for moonworts (Wagner and Wagner 1994), and the upper Great Lakes region, along with the northwestern U.S. and nearby Canada, are two of the richest areas (Wagner 1998).

Twenty-three species of North American moonworts are now recognized (Wagner and Wagner 1994) compared to an earlier interpretation of only six (Clausen 1938). The problems in distinguishing moonwort species are considerable (Wagner and Wagner 1990), including the habit of different species of moonworts growing at one site, the natural variation in form due to microhabitat variability, their small size, and the difficulty of making good herbarium specimens. However, decades of work, primarily by Dr. Herb Wagner and associates, have clarified the taxonomy of the group, habitat preferences, and the ranges of individual species. Several rare species within subgenus *Botrychium* are now recognized in the Upper Great Lakes region.

B. lanceolatum var. *angustisegmentum* is one of the most commonly encountered moonworts in eastern North America (Wagner 1991), although it is considerably rarer at the western edge of its Great Lakes range, and is reported as extremely rare in Minnesota (USDA Forest Service 2000). Its habitat is mainly in shaded deciduous woods (Wagner and Wagner 1993).

NOMENCLATURE AND TAXONOMY

Scientific Name: *Botrychium lanceolatum* (Gmel.) Angstr. var. *angustisegmentum* Pease and Moore
Family: Ophioglossaceae; Adder's-Tongue Family
Common Name: Narrow triangle moonwort, Lance-leaf moonwort
Synonymy: *Botrychium angustisegmentum* (Pease and Moore) Fern.; *Botrychium lanceolatum* (Gmel.) Angstr. ssp. *angustisegmentum* (Pease and Moore) Clausen

DESCRIPTION OF SPECIES

General Description And Identification Notes

Botrychium lanceolatum var. *angustisegmentum* is an erect perennial herb to 30 cm tall, with a single pinnate frond (sterile blade) 1.5-9 cm long, and a fertile blade 1.5-4.5 cm long. The fertile frond does not arise separately near the ground but appears to be a continuation of the single vertical stipe of the sterile frond. The common stalk is dark brownish green, the trophophore blade is very shiny and dark green. Segments are narrow, with the ultimate lobes narrowly linear-oblong, and 1-2 mm wide; the blade tissue is thin but firm; pinnae and lobes are mostly sharply pointed. The roots are clustered and fleshy. (Wagner and Wagner 1993, NatureServe 2001)

Botrychium lanceolatum var. *angustisegmentum* is very similar to *B. lanceolatum* var. *lanceolatum*. The Ottawa National Forest reports that var. *lanceolatum* is present on the Forest (Sue Trull, pers. comm. April 2001), which, if verified, would represent a disjunct

occurrence from the variety's main range of western North America (there are also known occurrences in northern Quebec, Newfoundland, Greenland, and Eurasia) (Wagner and Wagner 1993). Other sources, including Wagner and Wagner (1993) and NatureServe (2001) do not report var. *lanceolatum* from the midwestern United States.

Botrychium lanceolatum var. *angustisegmentum* may be distinguished from var. *lanceolatum* by its succulent, green to yellow-green blade, and having middle and terminal blade segments which are more than 2 mm wide (exclusive of the lobes) (Wagner and Wagner 1993). In var. *lanceolatum*, the blade is firm and dark green, with the middle blade segments usually less than 2 mm wide.

There are a number of useful references for identifying members of this genus. 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]). Wagner and Wagner (1993) provide a key to distinguish the two varieties. 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

Stems producing one frond per season; main roots mostly 0.5-1 mm in diameter; stipes 2-21 cm long. Fertile leaf blade 1.5-9 cm long; sporangia 0.7-1 mm diameter, slightly immersed, mostly separated and exposing sporangiophore midrib. Sterile leaf blade 1.5-4.5 cm long, 1.5-6 cm wide, ovate-lanceolate, truncate to obtuse at the base, acute at the apex, pinnate-pinnatifid to 2-pinnate, with incised, acute pinna apices and entire, acute pinnule and segment apices; the segments narrowly triangular, dark green, shiny; margins entire; n=45 (Lellinger 1985, Wagner and Wagner 1993, Cody and Britton 1989).

LIFE HISTORY

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

Like all ferns, moonworts 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 moonwort 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 moonworts. 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. lanceolatum* var. *angustisegmentum* has not been specifically researched and there may be life history details specific to *B. lanceolatum* var. *angustisegmentum* that do not follow these general patterns for the genus. Lack of species-specific information on the life history of *B. lanceolatum* var. *angustisegmentum* is a detriment to developing successful management options.

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. They speculated that asexual reproduction may have evolved as an adaptation to the dry habitats that some of these moonwort species were found in. There have been no reports of gemma production in *B. lanceolatum* var. *angustisegmentum*, indicating that 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 (creating 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). Except for *B. mormo*, the sporangial opening to release the spores in most *Botrychium* 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 (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, Whittier 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, 1996). Essentially the *Botrychium* gametophyte becomes a parasite of the mycorrhizal fungus (Casson et al. 1998, Whittier 2000).

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 (Wagner et al. 1985),

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, probably 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 the 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). *B. mormo* plants do not produce aboveground sporophytes more than two consecutive years (Johnson-Groh 1998) and there may be gaps as long as 6 years, although 1–3 years is more typical (Johnson-Groh 1998, Tans and Watermolen 1997). *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.

B. lanceolatum var. *angustisegmentum* plants emerge from the ground in late spring or early summer (Wagner and Wagner 1993). The loss of plants to herbivory, fire, and collection did not affect the return of moonworts in later years (Johnson-Groh and Farrar 1996a, b). *Botrychium* may depend little on photosynthesis. Mycorrhizae alone may supply a significant amount of the plant's nutrients and energy (Johnson-Groh 1999, Casson et al. 2000).

Available information indicates that members of subgenus *Botrychium* (moonworts) are short-lived perennials while subgenus *Sceptridium* (grapeferns) are more long-lived (Montgomery 1990, Muller 1993, Kelly 1994, Lesica and Ahlenslager 1996). 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).

Numerous hybrids between different species of moonworts have been found (Wagner et al. 1985, Wagner 1991, Wagner 1993). Wagner and Wagner (1988) described a hybrid between *B. lanceolatum* var. *angustisegmentum* and *B. matricariifolium* from Michigan. The hybrids possessed abortive spores and were intermediate in characteristics between the presumed parents (Wagner 1993). All 23 taxa of moonworts have chromosome numbers based on 45, half the members are tetraploids, and one is a hexaploid (Wagner 1993). Chromosome number has been useful in recognizing the distinctness of a new species; additionally, some species may have arisen through allopolyploids of interspecific hybrids (Wagner 1993). Farrar and Wendel (1996) have applied enzyme electrophoresis to the genetic relationships of eastern moonworts and have also suggested some relationships for moonwort species and hybrids. *B. lanceolatum* var. *angustisegmentum* is considered one putative parent for several species in the *B. matricariifolium* complex. They also found that the *B. lanceolatum* var. *angustisegmentum* of eastern North America was genetically distinct from the western variety *B. lanceolatum* var. *lanceolatum.*

HABITAT

Botrychium lanceolatum var. *angustisegmentum* occurs mainly in shaded woods throughout its range (Wagner and Wagner 1993). Lellinger (1985) described the habitat as in woods on cool to warm, mostly rich, subacid soil, and on hummocks in swamps.

In Michigan, the species occurs in a variety on mixed hardwood forests and forest edges, and in disturbed areas such as old logging roads and skid-trails. Plants are largely absent forest stands less than 25 years old (USDA Forest Service 2000).

In Wisconsin, closed-canopy mesic northern hardwood stands are the preferred habitat; sites are generally similar to those supporting *B. mormo* (USDA Forest Service 2000).

Rook (2001) from Minnesota, described the habitat as dry, or more often damp, partially shaded areas in coniferous or rich deciduous forests, or in moist grassy or rocky areas. A preference for northern hardwood habitats in Minnesota is reported (USDA Forest Service 2000). There are 16 known locations of *Botrychium lanceolatum* var. *angustisegmentum* on the Chippewa National Forest. Associated habitats include: northern hardwoods, aspen and birch woods with a balsam-fir understory, low areas in a black ash/elm/maple habitat with balsam-fir and maple understory, old aspen stand with maple, ash, and basswood, along a drainage through an alder thicket, and an aspen and ash woods near a swampy area. There are also three populations reported from the Superior National Forest.

Following is a review of state and provincial habitats from NatureServe (2001):

Connecticut: Acid talus slope woodland and sphagnum hummock in swamp growing with poison ivy and *Botrychium oneidense*.
Michigan: This taxon is widespread and locally common in moist hardwood forests of sugar maple, yellow birch, and basswood on the Ottawa National Forest (pers. comm. Sue Trull, Ottawa NF 2000).

Ontario: In mesic deciduous and mixed woodlands including floodplains. Soils are slightly acid, silty clay loams, poorly drained, and have a high organic content. Associated plants include red oaks, black oaks, sugar maple, cherry, white ash, yellow birch, eastern hemlock, *Dryopteris intermedia*, and *Toxicodendron radicans*.
Rhode Island: Along ridgetops.
Virginia: Cool mesic maple-birch woods; old second growth pasture woods; elevation 3600 feet.
Vermont: In rich, mesic forest with mature sugar maple, white ash, and basswood. It also occurs in *Thuja occidentalis* swamps. Other sites in Vermont occur on old pastureland that is returning to forest.
West Virginia: Associated with rich sugar maple-yellow birch woods, choke cherry, *Crataegus*, and *B. matricariifolium.*

DISTRIBUTION, ABUNDANCE, AND STATUS

Botrychium lanceolatum var. *angustisegmentum* ranges from Newfoundland east to Minnesota, and south to Virginia and Tennessee; and from Tennessee northwest to Minnesota. This variety is most rare in the states which are on the southern and western edges of its range. On the Ottawa National Forest of Michigan's Upper Peninsula, this taxon is quite common (pers. comm. Sue Trull, Ottawa NF, 2000; NatureServe 2001).

North American range of Botrychium lanceolatum var. angustisegmentum (Wagner and Wagner 1993).

In Minnesota, occurrence records exist for 84 locations in 10 counties (Minnesota Natural Heritage Program 2000, Appendix A). The occurrence records are mostly from the 1990s, probably indicative more of the intensity of the search effort rather than any increase in the species' population.

In Wisconsin and Michigan, locations of this species are not tracked by the respective natural heritage programs.

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: G5T4 (May 1995)
Rounded Global Conservation Status Rank: T4
Global Conservation Status Rank Reasons: *B. lanceolatum* var. *angustisegmentum* is fairly common over a relatively broad range. It is threatened primarily by logging of mature hardwood forest.

United States: National Conservation Status Rank: N4 (December 1994)
Canada: National Conservation Status Rank: N? (August 1993)

Distribution and Conservation Status in the United States
Connecticut (SR), Kentucky (SR), Maine (SU), Maryland (SR), Massachusetts (S2S3), Michigan (S4), Minnesota (SR; state threatened), New Hampshire (SR), New Jersey (S3), New York (S4), North Carolina (S1), Ohio (SX), Pennsylvania (SR), Rhode Island (S1), Tennessee (SR), Vermont (S3), Virginia (S1), West Virginia (S1), Wisconsin (S3)

Distribution and Conservation Status in Canada
New Brunswick (SR), Newfoundland (SH), Newfoundland Island (Newfoundland) (SR), Nova Scotia (S2), Ontario (S3), Prince Edward Island (S1), Quebec (S3)

EO SUMMARY

GREAT LAKES STATES – NUMBER OF ELEMENT OCCURRENCES

State	No. of EOs	State Rank	Status	Comments
Minnesota	84	SR	T	
Wisconsin	na	S3	none	Not tracked in state
Michigan	na	S4	none	Not tracked in state
Total	na			

STATE and NATIONAL FORESTS - SUMMARY OF ELEMENT OCCURRENCES

National Forest	No. of EOs
Minnesota	84
Chippewa National Forest	16
Superior National Forest	3
Michigan	na
Ottawa National Forest	na
Hiawatha National Forest	na
Huron-Manistee National Forest	na
Wisconsin	na
Chequamegon-Nicolet National Forest	na
Total State EOs (MN only)	84
Total National Forest EOs (MN only)	19
NF as % of EOs in MN only	23%

POPULATION BIOLOGY AND VIABILITY

Little information is available about the population biology of *B. lanceolatum* var. *angustisegmentum*. Population studies on other species of moonworts have shown that there is 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 1998, 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 *Botrychium 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. lanceolatum* var. *angustisegmentum* may respond similarly.

Many species of *Botrychium* are associated with light to moderate disturbances (Lellinger 1985, Wagner and Wagner 1993). Habitat reports for *B. lanceolatum* var. *angustisegmentum* are usually in forested environments with a less active disturbance regime. The species is apparently tolerant of, but not dependent on, some level of disturbance (USDA Forest Service 2000).

POTENTIAL THREATS AND MONITORING

Threats to *B. lanceolatum* var. *angustisegmentum* include exotic earthworms, invasion of sites by garlic mustard (*Alliaria petiolaria*) and possibly other exotic plants, timber harvesting, road building, and land use changes that affect drainage (USDA Forest Service 2000). Another source lists the principal threat to *Botrychium lanceolatum* var. *angustisegmentum* as the logging of mature hardwood forests (NatureServe 2001). Deforestation can result in soil desiccation, which is a threat to this plant (NatureServe 2001). Forest clearing for second home development also poses a threat (NatureServe 2001).

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). Plants may also be collected by herbalists due to perceived medicinal powers (USDA Forest Service, Eastern Region 1999).

In a French study (Muller 1992), drought-like conditions resulted in wilted sporophytes of *Botrychium matricariifolium* 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, 1964; Cothrel et al. 1997, Nixon 1995). 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. lanceolatum* var. *angustisegmentum* and its habitat is uncertain, but since it is often reported in northern hardwood forests, there may be significant impacts, similar to those reported for *B. mormo* (Sather et al. 1998).

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 O 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), whereas 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 litter/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 moonworts. Of all species of *Botrychium,* the most studied has been *B. mormo*. A comparison of 6 plots with earthworms compared to 6 plots without worms (a relatively small sample size however) on the Chippewa National Forest 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, 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). Since the habitat favored by *B. mormo* is generally similar to the forested habitat of *B. lanceolatum* var. *angustisegmentum,* there may be reason for concern about the impacts of earthworms on *B. lanceolatum* var. *angustisegmentum.*

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 2000, NatureServe 2001), but no research has been reported on the response of *Botrychium lanceolatum* var. *angustisegmentum* populations to management of any kind. A no-impact buffer surrounding populations is recommended for other *Botrychium* species with similar habitat requirements (NatureServe 2001).

Efforts at transplantation have not been successful. Relocated and overwintered plants have been reported to produce aboveground parts only once before dying (F. Wagner reported in NatureServe 2001).

Research and monitoring requirements

Like all *Botrychium*, *B. lanceolatum* var. *angustisegmentum* is fairly small, inconspicuous, and difficult to find (unless one is specifically looking for it). *Botrychium* may go dormant and not appear aboveground in a given growing season (Lesica and Ahlenslager 1996). Due to these factors, there are almost certainly undiscovered sites for this species, and where rare, inventories for the plant should continue.

While some research data have been developed about population fluctuations for certain species of moonworts (Johnson-Groh 1999), specific information for *B. lanceolatum* var. *angustisegmentum* population biology is lacking. As a result, research opportunities exist on nearly every aspect of the ecology of *B. lanceolatum* var. *angustisegmentum*, including basic life-history information (germination requirements, growth requirements, life span, etc.), habitat requirements, and management needs (NatureServe 2001)

Almost no information is available on *B. lanceolatum* var. *angustisegmentum* life history in relation to disturbance, succession, and colonization of new sites. It is unclear how *B. lanceolatum* var. *angustisegmentum* 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 have been suggested by Ostlie (1990) and Johnson-Groh (1999).

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). 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 actions.

Specific information on *B. lanceolatum* var. *angustisegmentum* 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), and it can be inferred that other *Botrychium* may respond in a similar manner.

Berlin et al. (1998) make a number of specific research and monitoring recommendations for the moonwort, *B. mormo*. Many of their suggestions likely apply to other *Botrychium* species; that source should be consulted for detailed recommendations about *Botrychium* monitoring and research techniques and needs. There are also a number of specific suggestions about habitat and population monitoring for *B. rugulosum* that generally apply to most uncommon *Botrychium* spp. at www.natureserve.org (NatureServe 2001):

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 should be mapped as an aid to tracking, possibly providing detailed information pertaining to 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.

NatureServe (2001) also reports that the Monongahela National Forest monitors the presence/absences of this species within the forest and suggests that the Ottawa National Forest could be a useful site for monitoring populations of this taxon.

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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 Lanceolatum* Var. *Angustisegmentum* 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 0 (not tracked)
Minnesota 84
Wisconsin 0 (not tracked)

Minnesota

Location: Minnesota, Aitkin County
Ownership: Other public
Abundance: Not listed
Habitat: Plants occur in a 'postage stamp'-sized deciduous forest dominated by *Acer saccharum* and *Tilia americana*. *Botrychium oneidense, B. matricariifolium*; both forms of *B. dissectum* also occur at this site.
Comments: 1991 listing
Source of information: Minnesota Natural Heritage Program Element Occurrence Record

Location: Minnesota, Aitkin County
Ownership: State
Abundance: Not listed
Habitat: Low narrow wooded rise between two ash swamps. Dominated by *Acer saccharum* and *Tilia americana*. Moist gravelly soils.
Comments: 1993 listing
Source of information: Minnesota Natural Heritage Program Element Occurrence Record

Location: Minnesota, Aitkin County
Ownership: Unknown
Abundance: Very infrequently observed.
Habitat: Plants occur in a hardwood stand dominated by *Acer saccharum* and *Tilia americana*. Associated with *Botrychium virginianum, B. matricariifolium, Uvularia grandiflora, Trillium grandiflorum.*
Comments: 1996 listing
Source of information: Minnesota Natural Heritage Program Element Occurrence Record

Location: Minnesota, Aitkin County
Ownership: Unknown
Abundance: Not listed

Habitat: In a hardwood forest at a transition zone between maple/basswood and ash. Associated with *Botrychium virginianum*.
Comments: 1996 listing
Source of information: Minnesota Natural Heritage Program Element Occurrence Record

Location: Minnesota, Aitkin County
Ownership: Unknown
Abundance: Not listed
Habitat: Hardwood forest dominated by *Acer saccharum* and *Tilia americana*. Associated with *Botrychium multifidum, B. matricariifolium*.
Comments: 1996 listing
Source of information: Minnesota Natural Heritage Program Element Occurrence Record

Location: Minnesota, Aitkin County
Ownership: Unknown
Abundance: Not listed
Habitat: 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,* and *B. mormo*.
Comments: 1996 listing
Source of information: Minnesota Natural Heritage Program Element Occurrence Record

Location: Minnesota, Aitkin County
Ownership: State
Abundance: Not listed
Habitat: Along small drainage in candidate old-growth maple-basswood forest with *Botrychium multifidum, Botrychium matricariifolium, Aralia racemosa, Thelypteris phegopteris, Gymnocarpium dryopteris, Uvularia sessilifolia,* and *Polygonatum pubescens.*
Comments: 1996 listing
Source of information: Minnesota Natural Heritage Program Element Occurrence Record

Location: Minnesota, Aitkin County
Ownership: Unknown
Abundance: 25-30 plants
Habitat: Local in mature northern hardwood forest. Canopy dominated by *Acer saccharum* and *Tilia americana*. Understory of *Acer saccharum* and *Carpinus caroliniana*. Associated with *Botrychium matricariifolium, Athyrium angustum, Uvularia sessilifolia, Thalictrum dioicum, Osmorhiza claytonii, Luzula acuminata, Carex arctata*. Rocky soil.
Comments: 1996 listing
Source of information: Minnesota Natural Heritage Program Element Occurrence Record

Location: Minnesota, Aitkin County
Ownership: Unknown
Abundance: Rare to locally frequent; 50+ plants in 1 acre low area with higher moisture than surrounding forest floor.

Habitat: Mature maple-basswood forest. Canopy locally of *Fraxinus nigra*, *Acer saccharum* and *Tilia americana*. Soil with thick, moist, organic layer over rocky loam. Sparse herbaceous cover. Associated with *Botrychium matricariifolium, B. oneidense, Athyrium angustum, Lycopodium lucidulum, Maianthemum canadense,* and *Acer saccharum* seedlings.
Comments: 1996 listing
Source of information: Minnesota Natural Heritage Program Element Occurrence Record

Location: Minnesota, Aitkin County
Ownership: Unknown
Abundance: 12 plants in 30 acres
Habitat: Mature northern hardwood forest dominated by *Acer saccharum, Tilia ameicana, Fraxinus pensylvanica* and *Betula papyrifera*. In low areas and around fringes of small upland island surrounded by ash swamp. Associated with *Botrychium matricariifolium, B. virginianum, Athyrium angustum, Acer saccharum* seedlings, *Circaea alpina, Equisetum sylvaticum*. In thick leaf litter in sparsely vegetated areas.
Comments: 1996 listing
Source of information: Minnesota Natural Heritage Program Element Occurrence Record

Location: Minnesota, Aitkin County
Ownership: State and private
Abundance: 11 plants
Habitat: Maple-basswood forest associated with *Clintonia borealis, Arisaema triphyllum, Carex pensylvanica, Asarum canadense* and *Parthenocissus inserta.*
Comments: 1997 listing
Source of information: Minnesota Natural Heritage Program Element Occurrence Record

Location: Minnesota, Aitkin County
Ownership: Unknown
Abundance: several plants
Habitat: In a low moist area of maple and ash near a beaver pond, several plants seen. Along a deer trail on a forested slope dominated by *Acer saccharum* and *Tilia americana*, only a few plants seen.
Comments: 1997 listing
Source of information: Minnesota Natural Heritage Program Element Occurrence Record

Location: Minnesota, Aitkin County
Ownership: Unknown
Abundance: several plants
Habitat: At the edge of a wet ashy area at the base of a forested slope dominated by *Acer saccharum* and *Tilia americana.*
Comments: 1997 listing
Source of information: Minnesota Natural Heritage Program Element Occurrence Record

Location: Minnesota, Aitkin County
Ownership: Unknown
Abundance: 15 plants

Habitat: Habitat is maple-basswood forest grading to aspen/black ash.
Comments: 1996 listing
Source of information: Minnesota Natural Heritage Program Element Occurrence Record

Location: Minnesota, Aitkin County
Ownership: County
Abundance: Plants patchy but not uncommon in forest.
Habitat: Maple-basswood forest with *Fraxinus pensylvanica, Athyrium angustum, B. multifidum,* and *B. matricariifolium.*
Comments: 1997 listing
Source of information: Minnesota Natural Heritage Program Element Occurrence Record

Location: Minnesota, Aitkin County
Ownership: County
Abundance: Plants patchy but scattered through forest.
Habitat: Maple-basswood forest with *Betula alleghaniensis, Arisaema triphyllum, B. matricariifolium,* and *B. multifidum.*
Comments: 1997 listing
Source of information: Minnesota Natural Heritage Program Element Occurrence Record

Location: Minnesota, Aitkin County
Ownership: State
Abundance: Plants patchy.
Habitat: Maple-basswood forest with *Betula alleghaniensis* and *Athyrium angustum*. Plants patchy in woods, occasionally with *B. matricariifolium.*
Comments: 1997 listing
Source of information: Minnesota Natural Heritage Program Element Occurrence Record

Location: Minnesota, Aitkin County
Ownership: State
Abundance: 6 plants.
Habitat: Maple-basswood forest with numerous sugar maple seedlings, *Uvularia sessilifolia* and *B. matricariifolium. B. mormo* also within 15m.
Comments: 1997 listing
Source of information: Minnesota Natural Heritage Program Element Occurrence Record

Location: Minnesota, Aitkin County
Ownership: State
Abundance: 12 plants.
Habitat: Maple-basswood forest with *Betula alleghaniensis*. Gradual sloping terrace with ne aspect. Assoc. spp include *B. multifidum, Uvularia grandiflora.*
Comments: 1997 listing
Source of information: Minnesota Natural Heritage Program Element Occurrence Record

Location: Minnesota, Aitkin County
Ownership: County

Abundance: not listed
Habitat: Maple-basswood forest transitioning into black ash wetland. Assoc. spp. include *Asarum canadense* and *Acer saccharum* seedlings with *B. mormo* and *B. matricariifolium* nearby.
Comments: 1997 listing
Source of information: Minnesota Natural Heritage Program Element Occurrence Record

Location: Minnesota, Aitkin County
Ownership: USFWS
Abundance: 4 plants.
Habitat: Upper edge of vernally, wet depression in maple-basswood-ash forest. Other assoc. spp. include *Ilex verticillata, Ulmus americana* saplings, *Athyrium angustum, B. matricariifolium*.
Comments: 1997 listing
Source of information: Minnesota Natural Heritage Program Element Occurrence Record

Location: Minnesota, Aitkin County
Ownership: County
Abundance: 42 plants.
Habitat: Approx 6 plants observed at edge of *Fraxinus* wet inclusion and *Acer saccharum, A. rubrum* and *Tilia americana* upland (subtle elevation changes). Assoc. spp. include *Athyrium angustum, Streptopus roseus, Arisaema triphyllum,* etc. Second collection made just south of 1st site (36 plants observed).
Comments: 1997 listing
Source of information: Minnesota Natural Heritage Program Element Occurrence Record

Location: Minnesota, Aitkin County
Ownership: County
Abundance: not listed
Habitat: Mixed hardwood forest primarily of maple-basswood and red oak. Plants beneath two large *Pinus strobus* in needle/leaf litter, with *Rubus pubescens, Rhus radicans, B. matricariifolium* and *B. simplex* var. *tenebrosum* (nearby).
Comments: 1997 listing
Source of information: Minnesota Natural Heritage Program Element Occurrence Record

Location: Minnesota, Aitkin County
Ownership: County
Abundance: Approx 24 plants observed.
Habitat: Maple-basswood-ash forest. Leafy depression with little to no vegetation. Plants from midway to 3/4 the way up the side of depression. Assoc. spp. include a few *Dryopteris carthusiana* and *Arisaema triphyllum.*
Comments: 1997 listing
Source of information: Minnesota Natural Heritage Program Element Occurrence Record

Location: Minnesota, Aitkin County
Ownership: State

Abundance: Not listed
Habitat: In old maple-basswood forest. With *Thelypteris phegopteris, Clintonia borealis, Brachyelytrum erectum, Aralia nudicaulis, Streptopus roseus, Ribes triste, Equisetum scirpoides.*
Comments: 1998 listing
Source of information: Minnesota Natural Heritage Program Element Occurrence Record

Location: Minnesota, Aitkin County
Ownership: County
Abundance: < 20 plants
Habitat: Growing in a one acre patch of northern hardwood forest at the base of a north-facing slope, adjacent to a hardwood swamp. Surrounding uplands are young oak/aspen forest. With *Acer saccharum, Gymnocarpium dryopteris, Asarum canadense* and *Carex rosea*.
Comments: 1997 listing
Source of information: Minnesota Natural Heritage Program Element Occurrence Record

Location: Minnesota, Aitkin County
Ownership: County
Abundance: 6 plants
Habitat: Growing in a mesic hardwood forest bordering a large ne-sw trending black ash swamp. Plants located under a sugar maple on a slight n-facing slope along a deer trail. With *B. matricariifolium*, not under basswood or oak trees.
Comments: 1998 listing
Source of information: Minnesota Natural Heritage Program Element Occurrence Record

Location: Minnesota, Aitkin County
Ownership: County
Abundance: 5-10 plants
Habitat: Growing in a mesic hardwood forest (not obviously northern or southern in character) on a shady s-facing slope along the north border of a long, ne-sw trending black ash swamp. Associates: *Athyrium angustum, Hepatica americana, Trillium grandiflorum, Uvularia sessilifolia, Galium triflorum*. Only 5-10 plants seen here, although area along swamp edge searched for 2 km ne.
Comments: 1998 listing
Source of information: Minnesota Natural Heritage Program Element Occurrence Record

Location: Minnesota, Aitkin County
Ownership: County
Abundance: Only 4 shoots seen (1 cluster) within 100m stretch of same habitat.
Habitat: Growing in a rare, lowland forest dominated by *Thuja occidentalis* and *Acer saccharum*. In shade under *Acer*, sparse woody understory. With *Asarum canadense, Uvularia sessilifolia, Carex pedunculata, Botrychium matricariifolium,* and *Mitella diphylla*.
Comments: 1998 listing
Source of information: Minnesota Natural Heritage Program Element Occurrence Record

Location: Minnesota, Aitkin County
Ownership: State
Abundance: Rare.
Habitat: Growing in a mature wet-mesic northern hardwood forest (*Tilia americana, Betula papyrifera, Fraxinus nigra* canopy). On a small terrace near the margin of lake. Deer trails and old logging trails. Flat microtopography. Among small herbs in assoc. with *Matteuccia struthiopteris, Rubus pubescens, Hydrophyllum virginianum* and *Equisetum arvense.*
Comments: 1998 listing
Source of information: Minnesota Natural Heritage Program Element Occurrence Record

Location: Minnesota, Aitkin County
Ownership: Unknown
Abundance: At least 25 shoots in 400 sq m releve plot; just beginning to shed spores.
Habitat: Growing in a lowland hardwood forest ecotone between wet meadow and disturbed northern hardwood. Restricted to this zone; canopy of *Populus tremuloides, Acer rubrum* and *Fraxinus pensylvanica,* with *Corylus cornuta, Matteuccia struthiopteris,* and *Asarum canadense* below.
Comments: 1996 listing
Source of information: Minnesota Natural Heritage Program Element Occurrence Record

Location: Minnesota, Aitkin County
Ownership: State
Abundance: 3 plants.
Habitat: In a young forest with a near-continuous canopy of *Acer rubrum, Betula alleghaniensis, Fraxinus nigra*.
ecotonal between lowland hardwood forest and white cedar swamp.
Comments: 1999 listing
Source of information: Minnesota Natural Heritage Program Element Occurrence Record

Location: Minnesota, Aitkin County
Ownership: State, other
Abundance: 4 plants.
Habitat: In a maple-basswood forest occupying the lower portion of a glacial beach ridge. Assoc: *Athyrium angustum, Carpinus caroliniana, Sanicula marilandica, Festuca obtusa*. Fine sand. Humus 7cm thick. Plants found mixed with *B. simplex* and 100's of *B. matricariifolium.*
Comments: 1999 listing
Source of information: Minnesota Natural Heritage Program Element Occurrence Record

Location: Minnesota, Aitkin County
Ownership: County
Abundance: 15 plants found within 100 sq meters.
Habitat: In a maple-basswood forest on near-level topography <3m above a large wetland 60m away. Species restricted to the low spots of the microtopography. Assoc: *Botrychium multifidum, B. matricariifolium, Athyrium angustum, Aster macrophyllus, Thalictrum dioicum, Carex pedunculata, Hepatica americana*. Thick and spongy humus.

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

Location: Minnesota, Beltrami County
Ownership: USFS
Abundance: Not listed
Habitat: Located in northern hardwoods with sugar maple-basswood.
Comments: 1996 listing
Source of information: Minnesota Natural Heritage Program Element Occurrence Record

Location: Minnesota, Carlton County
Ownership: State
Abundance: 10 plants
Habitat: Maturing northern hardwood forest dominated by *Tilia americana* and *Acer saccharum*. Rare and local in moister soil in and around small shallow depression created by old tree tip-up. Associated with *Botrychium matricariifolium, B. virginianaum, Athyrium angustum, Trientalis borealis, Galium triflorum, Aralia racemosa, Abies balsamea, Acer spicatum, A. rubrum, Ostrya virginiana*.
Comments: 1996 listing
Source of information: Minnesota Natural Heritage Program Element Occurrence Record

Location: Minnesota, Carlton County
Ownership: State
Abundance: not listed
Habitat: Growing in a narrow zone of lowland hardwood forest between maple-basswood forest and lake margin of *Alnus incana*. Under young *Tilia americana* and *Fraxinus nigra* canopy, *Corylus cornuta* below.
Comments: 1996 listing
Source of information: Minnesota Natural Heritage Program Element Occurrence Record

Location: Minnesota, Cass County
Ownership: USFS
Abundance: 1 plant
Habitat: Located in ash, elm, maple, with balsam, maple understory. Low area, probably wet in spring.
Comments: 1996 listing
Source of information: Minnesota Natural Heritage Program Element Occurrence Record

Location: Minnesota, Cass County
Ownership: USFS
Abundance: not listed
Habitat: Plants located in 2 areas in ne-central part of maple-basswood stand type. First area in hazel brush, site further to the west in cinnamon fern. Found on north side of large wetland, approx 25m north of wetland edge. North boundary of wetland dominated by cinnamon fern. Associated spp: sarsaparilla, Solomon’s-seal, large leaf aster and hazel.
Comments: 1996 listing

Source of information: Minnesota Natural Heritage Program Element Occurrence Record

Location: Minnesota, Cass County
Ownership: USFS
Abundance: 1 plant
Habitat: Along edge of wet depression near a well-defined deer trail. Habitat is maple-basswood forest with yellow birch. *Botrychium matricariifolium* also present at site. Associated spp: young maple, Solomon's-seal, grass spp., wild lily-of-the-valley, jack-in-the-pulpit, ostrich fern and *Equisetum* spp. Wet area with moderate humus content.
Comments: 1997 listing
Source of information: Minnesota Natural Heritage Program Element Occurrence Record

Location: Minnesota, Cass County
Ownership: USFS
Abundance: 2 plants
Habitat: Habitat is mature maple-basswood and oak next to wetland area. Open understory. Heavily shaded area with slight slope and very rich soil. Associated spp: young maples, jack-in-the-pulpit, sarsaparilla and large-leafed aster.
Comments: 1997 listing
Source of information: Minnesota Natural Heritage Program Element Occurrence Record

Location: Minnesota, Cass County
Ownership: USFS
Abundance: 5 plants
Habitat: Wet depression area. Habitat is mature aspen, maple-basswood and ash stand. Wet depression dominated by *Osmunda claytoniana*. Other associated species include young maples and *Botrychium matricariifolium.*
Comments: 1997 listing
Source of information: Minnesota Natural Heritage Program Element Occurrence Record

Location: Minnesota, Cass County
Ownership: USFS
Abundance: 1 plant
Habitat: Area is mostly flat with a very rich wet soil. Site is well shaded with a sparse understory. *Acer* is dominant tree species. Other associated spp include large-leaf aster and Solomon's-seal.
Comments: 1997 listing
Source of information: Minnesota Natural Heritage Program Element Occurrence Record

Location: Minnesota, Cass County
Ownership: USFS
Abundance: 3 plants
Habitat: Maple-basswood forest with ash and other hardwoods. Open under-story, rich organic layer. Forbs include ostrich fern, wild ginger, *Botrychium virginianum, B. matricariifolium, B. multifidum,* Solomon's-seal.
Comments: 1998 listing

Source of information: Minnesota Natural Heritage Program Element Occurrence Record

Location: Minnesota, Cass County
Ownership: USFS
Abundance: 50+ plants
Habitat: Located in maple-basswood with old age aspen. Site on edge of wetland with ash. Open understory with little to medium density forb layer. Associated spp: ostrich fern, dewberry, *Botrychium virginianum, B. multifidum*, sensitive fern, trillium spp, Solomon's-seal, *B. matricariifolium.*
Comments: 1998 listing
Source of information: Minnesota Natural Heritage Program Element Occurrence Record

Location: Minnesota, Cass County
Ownership: USFS
Abundance: 1 plant
Habitat: Found along drainage through alder thicket that forms shoreline of a large wetland. Associated spp: *Botrychium matricariifolium*, ostrich fern, moss spp.
Comments: 1998 listing
Source of information: Minnesota Natural Heritage Program Element Occurrence Record

Location: Minnesota, Cass County
Ownership: USFS
Abundance: 3 plants
Habitat: Found in mature maple-basswood forest with other mixed hardwoods.
Comments: 1999 listing
Source of information: Minnesota Natural Heritage Program Element Occurrence Record

Location: Minnesota, Cass County
Ownership: USFS
Abundance: 5 plants
Habitat: Found in moist, rich soil near swampy area in predominantly aspen and ash forest. Associated spp: *B. multifidum, B. virginianum,Bb. matricariifolium.*
Comments: 1999 listing
Source of information: Minnesota Natural Heritage Program Element Occurrence Record

Location: Minnesota, Cass County
Ownership: USFS
Abundance: 3 plants
Habitat: Plants found in mature maple-basswood forest with organic layer.
Comments: 1999 listing
Source of information: Minnesota Natural Heritage Program Element Occurrence Record

Location: Minnesota, Cook County
Ownership: unknown
Abundance: 3 plants

Habitat: Populations located in undisturbed northern hardwood forest dominated by *Acer saccharum.*
Comments: 1995 listing
Source of information: Minnesota Natural Heritage Program Element Occurrence Record

Location: Minnesota, Cook County
Ownership: USFS
Abundance: 1 plants
Habitat: Plant located in open field, sandy soil, of an old logging landing and sawmill in jack pine and red pine association. Evidence of recent fire. Associated spp: *Danthonia spicata, Fragaria virginiana, Anaphalis margaritacea, Schizachne purpurescens, Oryzopsis asperifolia, Antennaria neglecta, Viola adunca, Poa compressa, Trifolium hybridum, Cornus stolonifera, Salix humilis, Arctostaphylos uva-ursi, Vaccinium angustifolium,* and *Melampyrum lineare*. Seven other species of *Botrychium* found at same site.
Comments: 1998 listing
Source of information: Minnesota Natural Heritage Program Element Occurrence Record

Location: Minnesota, Cook County
Ownership: unknown
Abundance: 3 plants
Habitat: Three plants growing in middle of old abandoned winter logging trail traversing moderate southwest facing slope. Canopy cover 90%. Open understory. Mesic loamy soils, deep leaf litter. Associated spp include: *Acer* seedlings, *Corylus cornuta, Viola* sp., *Galium* sp., *Aralia nudicaulis, Maianthemum canadense, Streptopus roseus, Botrychium dissectum* var. *obliquum.*
Comments: 1998 listing
Source of information: Minnesota Natural Heritage Program Element Occurrence Record

Location: Minnesota, Itasca County
Ownership: USFS
Abundance: 6 plants
Habitat: Plants observed in a level area very near the lakeshore in a deciduous forest dominated by *Acer saccharum* and *Tilia americana,* with *Botrychium matricariifolium.*
Comments: 1994 listing
Source of information: Minnesota Natural Heritage Program Element Occurrence Record

Location: Minnesota, Itasca County
Ownership: USFS
Abundance: 5 plants
Habitat: Habitat includes maple saplings, yellow birch, ash, balsam and some ferns. Wet soil, area exposed to southern edge with cut-over. *B. matricariifolium* also present at site.
Comments: 1994 listing
Source of information: Minnesota Natural Heritage Program Element Occurrence Record

Location: Minnesota, Itasca County
Ownership: USFS

Abundance: 4 plants
Habitat: 4 plants located about 30 feet from a large cedar in a maple-basswood stand. Flat slope, shaded area, dominated by ferns. Associated species: *Botrychium virginianum* and *B. matricariifolium.*
Comments: 1997 listing
Source of information: Minnesota Natural Heritage Program Element Occurrence Record

Location: Minnesota, Itasca County
Ownership: unknown
Abundance: not listed
Habitat: Old-growth maple-basswood forest. Low area with sparse ground flora. With *Trillium cernuum* and *Athyrium angustum.*
Comments: 1998 listing
Source of information: Minnesota Natural Heritage Program Element Occurrence Record

Location: Minnesota, Kanabec County
Ownership: unknown
Abundance: 20 plants in 10m x 10m area
Habitat: Rare and local in rather moist level area just above level of nearby ash swamp. Mature maple-basswood forest. Associates in rather lush herb layer include *Botrychium matricariifolium, Athyrium angustum, Mitella diphyllum, Hydrophyllum virginianum, Osmorhiza claytoniana, Asarum canadense.*
Comments: 1996 listing
Source of information: Minnesota Natural Heritage Program Element Occurrence Record

Location: Minnesota, Kanabec County
Ownership: State
Abundance: 10 - 20 plants
Habitat: Maple-basswood forest dominated by maturing sugar maple 10-30 cm dbh on level gently sloping ground. Open canopy 75% cover due to frequent tip-ups. 10-20 moonworts in local area. Associated spp: *Acer saccharum, Betula papyrifera, Carex radiata, Trientalis borealis, Botrychium matricariifolium, Botrychium virginianum, Streptopus roseus, Uvularia grandiflora.*
Comments: 1999 listing
Source of information: Minnesota Natural Heritage Program Element Occurrence Record

Location: Minnesota, Kanabec County
Ownership: State
Abundance: Locally abundant on lower slopes
Habitat: Moderately well-drained, mesic soils. Maple-basswood forest dominated by sugar maple and basswood. Crowns 25-30 m tall, canopy closed cover with interrupted subcanopy. Mean dbh 35-40 cm. Associated spp: *Botrychium matricariifolium, Hydrophyllum virginianum, Uvularia grandiflora, Caulophyllum thalictroides.*
Comments: 1999 listing
Source of information: Minnesota Natural Heritage Program Element Occurrence Record

Location: Minnesota, Kanabec County
Ownership: State
Abundance: Rare
Habitat: Mesic forest dominated by quaking aspen and bur oak with a closed subcanopy of sugar maple, American elm and basswood. Soil gray clay with red streaks and unsorted pebbles. Associated spp: *Fragaria virginiana, Arisaema triphyllum, Trillium grandiflorum, Aralia nudicaulis, Athyrium angustum, Ribes cynosbati*.
Comments: 1999 listing
Source of information: Minnesota Natural Heritage Program Element Occurrence Record

Location: Minnesota, Kanabec County
Ownership: State
Abundance: Large population of moonworts extending over 1/4 mile along a river
Habitat: Mature maple-basswood forest selectively harvested. Canopy 15-20 m tall; mode dbh 20-30 cm; abundant max size 30-40 cm. Dominated by sugar maple and occasional red oak, basswood and black ash. Mesic, dark silt loam over clayey sand with unsorted pebbles. Large population of moonworts extending over 1/4 mile along a river. Associated spp: *Carpinus caroliniana, Botrychium matricariifolium.*
Comments: 1999 listing
Source of information: Minnesota Natural Heritage Program Element Occurrence Record

Location: Minnesota, Kanabec County
Ownership: State
Abundance: 10-20 moonworts in local area
Habitat: Maple basswood forest dominated by maturing sugar maple 10-30 cm dbh on level gently sloping ground. Open canopy 75% cover due to frequent tip-ups. *Carex radiata, trientalis borealis, Botrychium matricariifolium, Botrychium virginianum, Streptopus roseus, Uvularia grandiflora.*
Comments: 1999 listing
Source of information: Minnesota Natural Heritage Program Element Occurrence Record

Location: Minnesota, Lake County
Ownership: USFS
Abundance: <20 plants
Habitat: Plants growing along crown of old logging road and in small adjacent clearing. Associated spp: *Trifolium* sp., *Achillea millefolium,* short grasses, *Botrychium matricariifolium, B. simplex, B. spathulatum, B. hesperium, B. multifidum* and *B. minganense.*
Comments: 1993 listing
Source of information: Minnesota Natural Heritage Program Element Occurrence Record

Location: Minnesota, Lake County
Ownership: USFS
Abundance: 5 plants

Habitat: Five plants located in a shallow depression in mature sugar maple forest. Canopy closed, soil moist, rocky. Growing with *Botrychium matricariifolium, Thuja occidentalis, Clintonia borealis, Athyrium angustum* and *Betula alleghaniensis.*
Comments: 1995 listing
Source of information: Minnesota Natural Heritage Program Element Occurrence Record

Location: Minnesota, Mille lacs County
Ownership: State
Abundance: 12 plants
Habitat: Undulating end-moraine topography. 12 plants at base of a 1-2 degree nw-slope in an ecotone between northern hardwood forest and black ash swamp. Thick, spongy duff layer. Canopy includes *Quercus rubra, Tilia americana*, and *Acer saccharum.* Assoc: *Botrychium virginianum, B. simplex, B. matricariifolium, Carex pedunculata, Uvularia sessilifolia.*
Comments: 1999 listing
Source of information: Minnesota Natural Heritage Program Element Occurrence Record

Location: Minnesota, Mille lacs County
Ownership: State
Abundance: 10 plants
Habitat: 60-80 year old maple-basswood forest near a transition to black ash swamp. Species is restricted to the base of a 1-3 degree north slope at nearly the same elevation as the black ash swamp. Assoc: *Prunus virginiana, Corylus cornuta, Maianthemum canadense, Abies balsamea, Panax trifolium, Trillium grandiflorum.*
Comments: 1999 listing
Source of information: Minnesota Natural Heritage Program Element Occurrence Record

Location: Minnesota, Mille lacs County
Ownership: State
Abundance: 20+ plants
Habitat: Within 20m of the wet meadow fringe of a small tributary to the little Ann river. on the edge of a maple-basswood forest with a continuous canopy. Nearly level ground moraine topography. Assoc: *Aralia nudicaulis, Geranium maculatum, Milium effusum, Trientalis borealis, Uvularia sessilifolia, Asarum canadense*. Mull humus >5cm.
Comments: 1999 listing
Source of information: Minnesota Natural Heritage Program Element Occurrence Record

Location: Minnesota, Morrison County
Ownership: Unknown
Abundance: Not listed
Habitat: Cut over pine land (a few pine standing). Brushy second growth.
Comments: 1918 listing
Source of information: Minnesota Natural Heritage Program Element Occurrence Record

Location: Minnesota, Pine County
Ownership: Private

Abundance: 50+ plants
Habitat: Plants occur along the bank of a small stream in a deciduous forest dominated by *Acer saccharum* and *Tilia americana*. Spore capsules are fresh and immature (July 4th). *Botrychium matricariifolium, B. dissectum* var. *dissectum,* and *B. dissectum* var. *obliquum* also occur at this site.
Comments: 1993 listing
Source of information: Minnesota Natural Heritage Program Element Occurrence Record

Location: Minnesota, Pine County
Ownership: State
Abundance: Rare
Habitat: Plants occur in a low area in a deciduous forest dominated by *Acer saccharum*. Growing on old tip-up islands and in the moist soil in between with *Botrychium matricariifolium, Osmorhiza claytonii, Fraxinus nigra, Aralia racemosa,* and *Allium tricoccum*.
Comments: 1993 listing
Source of information: Minnesota Natural Heritage Program Element Occurrence Record

Location: Minnesota, Pine County
Ownership: State
Abundance: Rare
Habitat: Plants occur in a deciduous forest dominated by *Acer saccharum* and *Tilia americana*. *Botrychium mormo, B. matricariifolium, B. multifidum,* and *B. virginianum* also present at this site.
Comments: 1993 listing
Source of information: Minnesota Natural Heritage Program Element Occurrence Record

Location: Minnesota, Pine County
Ownership: private
Abundance: Rare
Habitat: Plants growing in a deciduous forest dominated by *Acer saccharum*. *Botrychium mormo, B. matricariifolium,* and *B. multifidum* also present
Comments: 1993 listing
Source of information: Minnesota Natural Heritage Program Element Occurrence Record

Location: Minnesota, Pine County
Ownership: State
Abundance: Rare
Habitat: Plants occur along a grassy, seldom-used road in a deciduous forest dominated by *Acer saccharum*. *Actaea pachypoda* and *Dryopteris intermedia* also present.
Comments: 1993 listing
Source of information: Minnesota Natural Heritage Program Element Occurrence Record

Location: Minnesota, Pine County
Ownership: State

Abundance: Several large, well-developed specimens, and numerous small ones observed at this site
Habitat: Plants occur in a deciduous forest dominated by *Acer saccharum*. Associated species include: *Ostrya virginiana, Cornus alternifolia, Clintonia borealis, viola pubescens,* and *Acer* seedlings. *Botrychium mormo* and *B. matricariifolium* also present.
Comments: 1993 listing
Source of information: Minnesota Natural Heritage Program Element Occurrence Record

Location: Minnesota, Pine County
Ownership: State
Abundance: Not listed
Habitat: Plants occur in a deciduous forest dominated by *Acer saccharum*. Associated species include: *Osmunda claytoniana, Streptopus roseus, Anemone quinquefolia,* and *Athyrium angustum. Botrychium matricariifolium, B. multifidum,* and *B. simplex* var. *tenebrosum* also occur at this site.
Comments: 1993 listing
Source of information: Minnesota Natural Heritage Program Element Occurrence Record

Location: Minnesota, Pine County
Ownership: State
Abundance: 10 plus plants
Habitat: Plants occur in a deciduous forest dominated by *Acer saccharum* and *Quercus rubra* that is situated at the base of a gentle slope. It is a moist area of small tree tip-up islands surrounded by black leaf litter.
Comments: 1993 listing
Source of information: Minnesota Natural Heritage Program Element Occurrence Record

Location: Minnesota, Pine County
Ownership: State
Abundance: 10 plus plants
Habitat: Plants occur in a moist area of tree tip-ups with *Ostrya virginiana, Cornus alternifolia, Viola pubescens, Asarum canadense, Botrychium virginianum, Acer saccharum,* and *Betula alleghaniensis.*
Comments: 1993 listing
Source of information: Minnesota Natural Heritage Program Element Occurrence Record

Location: Minnesota, Pine County
Ownership: Unknown
Abundance: Not listed
Habitat: Growing in second growth sugar maple stand (4-6 cm dbh) with scattered larger trees (39 cm dbh). Many cut stumps growing in moist soil under sugar maple litter off to side of shallow drainage way. Associated spp: *Maianthemum canadense, Clintonia borealis, Uvularia sessilifolia, Anemone quinquifolia, Dryopteris carthusiana, Botrychium matricariifolium,* and *B. simplex* var. *tenebrosum.*
Comments: 1993 listing
Source of information: Minnesota Natural Heritage Program Element Occurrence Record

Location: Minnesota, Pine County
Ownership: Unknown
Abundance: Several plants
Habitat: Several plants found in sugar maple (44 cm dbh) and basswood (23 cm dbh) between trail and
nearby black ash swamp. Numerous saplings (2-5 cm dbh) of sugar maple, basswood, and ironwood. Soil moist black loam over wetter silty clay. Scattered sugar maple leaf litter. Dom ground cover *Allium tricoccum*. Associated spp: *Actaea rubra, Aralia nudicaulis, Anemone quinquifolia, Aster macrophyllus, Solidago flexicaulis,* and *Arisaema atrorubens*.
Comments: 1993 listing
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 10 mi s of Holyoke. Canopy dominated by *Acer saccharum, A. rubrum, Quercus rubra, Tilia americana* with occassional *Fraxinus nigra, Betula alleghaniensis* and *Thuja occidentalis*. Moist/mesic soil on level ground moraine 50m from edge of black ash swamp. Associated with *Botrychium dissectum, B. matricariifolium, B. oneidense, Carex pedunculata, C. arctata, C. brunnescens, Athyrium angusta, Uvularia sessilifolia.*
Comments: 1995 listing
Source of information: Minnesota Natural Heritage Program Element Occurrence Record

Location: Minnesota, Pine County
Ownership: State
Abundance: 4 plants
Habitat: Rare and local in northern hardwood forest on small upland island surrounded by ash swamp. Sparsely vegetated low areas around fringe of island where vegetation begins to grade to swamp. Canopy of mature *Acer saccharum, A. rubrum, Fraxinus nigra* and *Betula alleghaniensis*. Associated with *Carex intumescens, Lycopodium lucidulum, Athyrium angustum* and *Acer saccharum* seedlings.
Comments: 1996 listing
Source of information: Minnesota Natural Heritage Program Element Occurrence Record

Location: Minnesota, Pine County
Ownership: State
Abundance: 4 plants in 2m x 2m area
Habitat: Northern hardwood forest. Canopy dominated by *Fraxinus nigra, Acer saccharum, A. rubrum,* and *Tilia americana*. Understory of *A. saccharum, Carpinus caroliniana* and *Corylus cornuta*. Moderately-well drained silt-loam. Approx 20m from edge of open streamside wetland. Associated with *Aster macrophyllus, Uvularia sessilifolia, Asarum canadense, Polygonatum pubescens,* moderately dense herb layer, fairly thick litter layerA
Comments: 1998 listing
Source of information: Minnesota Natural Heritage Program Element Occurrence Record

Location: Minnesota, Pine County
Ownership: Private
Abundance: Rare
Habitat: In a locally moist, species-rich portion of an oak forest dominated by *Quercus rubra*. Growing with *Tilia americana, Acer saccharum, Asarum canadense, anemone quinquefolia* and *Botrychium matricariifolium*. On a mini-terrace near small ravine.s
Comments: 1996 listing
Source of information: Minnesota Natural Heritage Program Element Occurrence Record

Location: Minnesota, Pine County
Ownership: Unknown
Abundance: 7 plants
Habitat: Soil is thin moist humus over rocky substrate. Dominant species are red maple, northern red oak, and paper birch, with balsam fir and arborvitae.
Comments: 1992 listing
Source of information: Minnesota 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

1. 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.

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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.
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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)