Conservation Assessment
For
Ternate Grapefern (Botrychium rugulosum)

Photo © by Steve Mortensen.

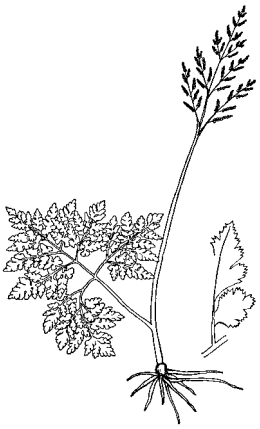

Illustration from Wherry (1995).

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This Conservation Assessment was prepared to compile the published and unpublished information and serves as a Conservation Assessment for the Eastern Region of the Forest Service.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

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EXECUTIVE SUMMARY

Botrychium rugulosum is a small fern that has been recognized as a distinct species only since 1982. It is extremely rare and local when found; its range extends from the Atlantic Provinces and southern Quebec in Canada to Minnesota, south to Connecticut, New York, Michigan, and Wisconsin. Its habitat is extremely variable, with plants occurring mostly in open areas but sometimes in shade. Many of the habitats have regular disturbance regimes. The largest threat to the species may be natural succession from opening to forest. Details about the biology of *B. rugulosum* are generalized from studies of other *Botrychium* species. Much of the life-cycle occurs underground. Numbers of aboveground sporophytes fluctuate and individual plants may not appear every year, complicating attempts to adequately inventory a population. Like other moonworts, *B. rugulosum* is dependent on a mycorrhizal relationship; thus species conservation must include consideration of this relationship. No specific information is available on managing habitat to maintain the species. Since plants are small and populations fluctuate in size, continued inventory efforts are necessary to better refine population demographics, species range, and habitat requirements. Much basic research on *B. rugulosum* biology is lacking.

INTRODUCTION/OBJECTIVES

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

The objectives of this document are to:

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

The genus *Botrychium*, family Ophioglossaceae, are small ferns that are typically divided into three subgenera in North America (Lellinger 1985). One subgenus, *Osmundopteris*, is only represented in our area by *B. virginianum*, the rattlesnake fern, which is common around much of the world (Wagner 1998). Subgenus *Botrychium*, the moonworts, includes numerous species of often rare, local, and very small plants that are difficult to find and identify. Subgenus *Sceptridium* (which includes *B. rugulosum*) are the grapeferns, medium-sized plants often termed 'evergreen,' but a more appropriate term might be 'wintergreen' since the old fronds die the following spring. Like the moonworts, the grapeferns and *B. rugulosum* have had a confused taxonomy in the past. *B. rugulosum* was considered to be the same species as a grapefern found in Asia, *B. ternatum*, until it was eventually recognized as a distinct species native to North America, formally described in 1982 (Wagner and Wagner 1982).

B. rugulosum can be found in a variety of habitats, and often these areas have been disturbed.

Open areas are the most common habitat but it is occasionally found in shaded forests. Grazed pastures are a common habitat in the New England area (Wagner and Wagner 1982). Succession may be a threat to *B. rugulosum* as open areas gradually succeed to closed-canopy forests. *B. rugulosum* often grows with and resembles two other grapeferns, *B. dissectum* and *B. multifidum*.

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

NOMENCLATURE AND TAXONOMY

- Scientific Name: *Botrychium rugulosum* W.H. Wagner
- Family: Ophioglossaceae; Adder's-Tongue Family
- Common Name: Ternate Grapefern, St. Lawrence Grapefern, Rugulose Grapefern
- Synonymy: *Botrychium ternatum* auct. non (Thunb.) Sw., *Botrychium multifidum* f. *dentatum* Tryon

DESCRIPTION OF SPECIES

General description and identification notes

Botrychium rugulosum was recognized as a distinct species within *Botrychium* subgenus *Sceptridium* (grapeferns) due to the combination of its geographical range, periodicity, blade-cutting, segment shapes, laminar contours and marginal teeth (Wagner and Wagner 1982). *B. rugulosum*, like all grapeferns, remains green through the winter with new leaves appearing in midspring. The name "*rugulosum*" refers to the tendency of the segments to become somewhat wrinkled and convex (Wagner and Wagner 1993). *B. rugulosum* is closely related to two more common species in the genus (and often occurring with them): *B. multifidum* in northern areas, and *B. dissectum* in the southern part of its range (Wagner and Wagner 1982). The long-stalked pinnae and the rather large space between the basal pair of pinnae and the upper parts help distinguish this species from *B. multifidum* (Lellinger 1985).

New leaves appear in *B. rugulosum* during late-May. There is a seasonal sequence in leaf development among several species of *Botrychium* that may grow in association with *B. rugulosum* (Wagner and Wagner 1982): *B. multifidum* tends to develop earliest in the season, followed by *B. oneidense, B. rugulosum,* and *B. dissectum*. Since the leaves develop slowly, the earlier species will have leaves noticeably more developed than those of later-developing species. In sunnier, more open locations, the stalk of the sterile blade will be shorter than those found in shade forms (Wagner and Wagner 1982).

Before distinguished as *B. rugulosum*, the species was considered to be a North American form of *B. ternatum*. Early information can be found in Wagner (1959, 1960a, 1960b, 1961, 1962). A key to identify individuals within *Botrychium* subgenus *Sceptridium* (grapeferns, which includes *B. oneidense, B. multifidum, B. rugulosum* and *B. dissectum*) can be found in Wagner and Wagner (1982). The treatment in Volume 2 of the Flora of North America

(Wagner and Wagner 1993) is the most current published guide to all but the most recently described species (for example, since the release of Volume 2, a new species, *Botrychium linear*e, has been described by Wagner and Wagner [1994]). Lellinger (1985) includes descriptions and color photographs of many moonwort species. Cody and Britton (1989) provide descriptions and distribution maps of *Botrychium* species known to that time in Canada.

Technical description

Wagner and Wagner (1982), in describing *B. rugulosum*, stated: "In habit resembling *B. dissectum* and *B. multifidum* with which it usually grows, its fronds emerging from the ground before the former and after the latter. Sterile blades deltoid, the stalk more or less the same length as the blade (shorter in sun forms, longer in shade forms), the stalk and blade together of mature, fertile plants averaging 8-16 cm (3 cm in sun to 30 in shade), the blade itself averaging 4-8 (2-16) cm long. Sterile blades 3-(2-4) pinnate, divided to the pinna tips with regular reduction in symmetry. Lateral and basal pinnae ovate-deltoid, the pinnules rhomboidal, ovate, or oblong, usually strongly angled, 0.2-0.5 cm wide, the laminar surface in the living state convex above and more or less coarsely rugulose. Pinnule margins with nearly regular, somewhat rounded, wide teeth (except in rare subentire forms). Lateral veins mainly somewhat spreading rather than nearly parallel. Chromosomes n= 45."

LIFE HISTORY

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

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

The following information is from research with a variety of *Botrychium* species. Reproduction in *B. rugulosum* has not been researched and there may be life history details specific to *B. rugulosum* that do not follow these general patterns for the genus. Lack of specific information on the life history of *B. rugulosum* is a serious management concern.

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

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

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

After the spores are released, they infiltrate into the soil and may germinate. Infiltration and subsequent germination may take up to 5 years, although some may germinate immediately (Casson et al. 1998). Spore germination requires darkness, (Whittier 1972, 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, Whittier 1996). Essentially the *Botrychium* gametophyte becomes a parasite of the mycorrhizal fungus (Casson et al. 1998, Whittier 2000). The underground gametophyte (subg. *Sceptridium*) is generally less than 0.3 cm in longest diameter, cylindrical or cushion shaped, moderately hairy, and light to dark brown-brown (Wagner et al. 1985).

All *Botrychium* species are believed to be obligately dependent on mycorrhizal relationships in both the gametophyte (Bower 1926, Campbell 1922, Gifford and Foster 1989, Scagel et al. 1966, Schmid and Oberwinkler 1994) and sporophyte generations (Bower 1926, Gifford and Foster 1989, Wagner and Wagner 1981). The gametophyte is subterranean and achlorophyllous, depending on an endophytic fungus for carbohydrate nutrition, while the roots of the sporophyte lack root hairs and probably depend on the fungus for absorption of water and minerals (Gifford and Foster 1989). *Botrychium* gametophytes were formerly

considered saprophytic (Bower 1926), but are now thought to obtain carbohydrates fixed by neighboring plants and transported by shared mycorrhizal fungi (Camacho 1996); they are thus better classified as myco-heterotrophic (Leake 1994).

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

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

Gametophytes and young sporophytes may exist underground for many years before an aboveground plant develops (Campbell 1911, Muller 1993). Mortality may be high during this period (Peck et al. 1990). The gametophyte produces male and female gametangia, fertilization of eggs occurs via free-swimming sperm under wet conditions (Lesica and Ahlenslager 1996). Most fertilizations are likely due to inbreeding, since the antheridia and archegonia are nearby and enzyme electrophoresis indicates a lack of genetic variability (McCauley et al. 1985, Soltis and Soltis 1986, Farrar and Wendel 1996, Farrar 1998). However, there is no reason that cross-fertilization should not occur (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 37 other species of ferns studied (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). For example, plants of *B. mormo* 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.

Grapeferns differ from moonworts in that the fertile part of the plant may often be absent during an individual growing season (Wagner 1998). *B. rugulosum* leaves appear in midspring, persist through the winter, then die the following spring (Wagner and Wagner 1993). If the leaf is damaged soon after emergence, a second leaf can appear, at least in the closely related *B. dissectum* (Montgomery 1990). The loss of plants to herbivory, fire and collection did not affect the return of moonwort species in later years (Johnson-Groh 1998, Johnson-Groh 1999). However, If grapeferns like *B. rugulosum* depend relatively more on photosynthesis than the mycorrhizal relationship as Johnson-Groh suggested in USDA Forest Service, Eastern Region (1999), then the loss of plants may have a more negative effect on the population.

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

While numerous hybrids between different species of moonworts (*Botrychium* subgenus *Botrychium*) have been found (Wagner et al. 1985; Wagner 1991, 1993), there are no grapefern hybrids reported from North America (Wagner 1993). Six of the seven grapefern species in North America are diploid with a chromosome number of 45, the seventh, *Botrychium jenmanii*, is the only tetraploid with n=90, a presumed ancient allopolyploid hybrid of two diploid species (Wagner 1993).

HABITAT

Botrychium rugulosum is sometimes referred to as St. Lawrence grapefern due to its range roughly paralleling the St. Lawrence Seaway, then extending west to Wisconsin and Minnesota. The species is known from Quebec and Ontario in Canada, and in the United States in Connecticut, Michigan, Minnesota, New York, Vermont, and Wisconsin (Wagner and Wagner 1982, 1993). It has been reported most commonly from Michigan and Vermont, but that may be due to the intensity of searches (Wagner and Wagner 1982).

Initial descriptions of the species reported that *B. rugulosum* typically occurred on sandy or silty soils, usually mixed with black organic matter (Wagner and Wagner 1982). Soil pH ranged from circumneutral to acidic (more commonly) at these sites.

In the southern part of its range, *B. rugulosum* is found most frequently in low, swampy areas, especially in older second-growth forests, grassy places, and along paths (Wagner and Wagner 1982). Old apple orchards that have been abandoned for 20 or more years, brushy old fields, and second-growth upland woods were productive sites for this species (Wagner and Wagner 1982). In southern locations (typified in Michigan by a region from Saginaw and St. Clair counties to Monroe County), grapeferns are usually found on rich sites, and plants of *B. rugulosum* reach their largest size, with sterile fronds 25 cm or more in length (Wagner and Wagner 1982). Associates there include *Acer rubrum, Cornus drummondii, C. racemosa, C. stolonifera, Corylus americanus, Populus tremuloides, Sassafras albidum, Ulmus americana, Vitis riparia, Asplenium platyneuron,* and species of *Anemone, Aster, Desmodium, Equisetum, Fragaria, Solidago,* and *Viola*.

In Vermont and New York, *B. rugulosum* was most abundant in actively grazed pastureland (Wagner and Wagner 1982). Grazing does not appear to cause any serious harm to the populations, although some individuals were trampled or apparently dwarfed in size. Where the grazing is most intense, *B. rugulosum* occurs in an almost lawn-like habitat (Wagner and Wagner 1982). Plant associates in these situations included *Dennstaedtia punctilobula, Pteridium aquilinum, Rubus idaeus, Comptonia peregrina, Spiraea alba, S. tomentosa, Juniperus virginiana,* and species of *Achillea, Antennaria, Danthonia, Fragaria, Gnaphalium, Hieracium, Lycopodium, Panicum, Plantago, Poa, Polygonum, Polytrichum, Prunella, Rumex* and *Viola*.

In northern localities, plant associates include haircap moss (*Polytrichum* spp.), *Gaultheria procumbens, Rubus hispidus, Acer rubrum, Betula papyrifera, Hamamelis virginiana, Populus tremuloides, Prunus serotina, Salix* spp., *Spiraea alba,* and *Vaccinium angustifolium* (Wagner and Wagner 1982). Also found were species within the genera *Antennaria, Fragaria, Hieracium, Lycopodium, Osmunda, Pteridium* and *Solidago*. A Minnesota report listed habitat preferences as dry areas with short grasses, bracken fern, sweet fern, jack pine, red pine, aspen/balsam-fir woods, and openings within these types (Grover 2000). Other habitats were described as margins of ephemeral pools in forests dominated by pines, spruce, and paper birch/aspen. Soil pH was near neutral (Grover 2000).

A summary of habitat requirements from the literature and element occurrence records for

Wisconsin and Minnesota (USDA Forest Service, Eastern Region 1999) is:

- few or no trees,
- shrubs more or less absent to moderately shrubby,
- a ground flora of grasses and forbs such as strawberry, hawkweed, and yarrow.

Microhabitats are typically sparsely vegetated; they may be dry but some sites occur along the edges of wet meadows. Lellinger (1985) described the habitat as old, brushy pastures, meadows, and wet woods; soils are sandy and acidic.

In Wisconsin, Brzeskiewicz (1999) reported an occurrence in loamy sand down the center grassy strip of an old logging road. Other locations listed were the grassy margins of ponds or seepage lakes, especially those with fluctuating water levels where the plants occur in the low-growing herbaceous zone between the water and the typical jack pine and aspen forest. She also noted that the plants may be moisture limited, since in sands they tend to occur in areas such as depressions with increased water-holding capacity. Wildfire was part of the disturbance regime in some of the pine barren and pine/oak habitats, possibly improving the habitat for *B. rugulosum* through removing brushy competition (Brzeskiewicz 1999).

Like many *Botrychium*, *B. rugulosum* often occurs with other species of the genus (Wagner and Wagner 1983). In the southern part of the range, *B. dissectum* is the common associate, while in the north, *B. multifidum* is typical (Wagner and Wagner 1982). Other *Botrychium* associates have been reported by Wagner and Wagner (1982, 1993), including *B. matricariifolium*, *B. simplex*, *B. oneidense*, and *B. virginianum*. They noted seven species of *Botrychium* at the type locality (Wagner and Wagner 1982).

DISTRIBUTION, ABUNDANCE, AND STATUS

Wagner (1998) described finding *Botrychium rugulosum* a “real botanist’s prize.” It is very rare and at the majority of known locations there are only one or a few individual plants (Wagner and Wagner 1982). Wagner and Wagner (1993) reported that *B. rugulosum* is often found in populations of only 5–10 individuals, but several populations number over 100 plants.

Rangewide, *B. rugulosum* occurs in a narrow east-west band, from the Atlantic Provinces in Canada to Minnesota, and a number of localities have been discovered only recently (Wagner 1998). In searching for the plant, almost invariably *B. multifidum* or *B. dissectum* was found first, with continued searching discovering plants *B. rugulosum* (Wagner and Wagner 1982). A number of new sites supporting this species likely remain to be discovered, especially in southern Ontario, the Upper Peninsula of Michigan, and in northern Wisconsin (Wagner and Wagner 1982).

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

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

Global Conservation Status Rank: G3
Rounded Global Conservation Status Rank: G3

United States: National Conservation Status Rank: N3 (1994)

Canada: National Conservation Status Rank: N2N3 (1997)

U.S. and Canada State/Province Conservation Status Ranks
United States: Connecticut (SR), Michigan (S3), Minnesota (S2), New York (S1), Vermont (S1S2), Wisconsin (S2).
Canada: New Brunswick (S1), Ontario (S2), Prince Edward Island (SU), Quebec (SH).

Brzeskiewicz (1999) summarized known sites but this list may not be comprehensive, as Wagner and Wagner (1982) listed several Michigan locations. In addition, some of the Wisconsin collections may have been misidentified (see notes in Appendix A).

State/Province	**# of sites**
New York	11 (2 extant in 2 counties; 9 historic in 5 counties)

Wisconsin	16 (in 4 counties)
Vermont	14 (statewide)
Minnesota	31 (in 9 counties)
Michigan	1 (Delta County)
Ontario	(16 counties)
Quebec	Data not available
Atlantic Provinces	3

EO SUMMARY

GREAT LAKES STATES – NUMBER OF ELEMENT OCCURRENCES

State	No. of EOs	State Rank	Status	Comments
Minnesota	31	S2	T	State threatened
Wisconsin	16	S2	SC	Special concern
Michigan	1	S3	--	
Total	48			

STATE and NATIONAL FORESTS - SUMMARY OF ELEMENT OCCURRENCES

National Forest	No. of EOs
Minnesota	31
Chippewa National Forest	5
Superior National Forest	0
Michigan	1
Ottawa National Forest	0
Hiawatha National Forest	1
Huron-Manistee National Forest	0
Wisconsin	16
Chequamegon-Nicolet National Forest	12
Total State EOs	48
Total National Forest EOs	18
NF as % of EOs in MN, WI, MI	38%

POPULATION BIOLOGY AND VIABILITY

Little information is available about the population biology of *B. rugulosum* and other grapeferns within subgenus *Sceptridium*. Relatively more information is available for

moonworts (subgenus *Botrychium*). Since the life-cycles are similar (Lesica and Ahlenslager 1996), moonwort information may have some applicability to grapefern biology. However, it should be applied with caution, recognizing that a significant management limitation is the lack of specific information on many aspects of *B. rugulosum* biology and ecology. Also to be considered is that while moonworts are short-lived perennials, grapeferns are longer lived plants (see Section C).

Population studies on species of moonworts have shown that there is considerable annual variation in the number of aboveground plants at a given site (Johnson-Groh 1999). She reported that populations fluctuated independently among plots at any given site, and some populations increased while others decreased (Johnson-Groh 1999). These variations may reflect microsite differences such as soil moisture, herbivory, or mycorrhizae, although populations of moonworts are known to fluctuate widely without any apparent cause (Johnson-Groh 1999). Individual plants typically do not emerge every year and may skip years (Lesica and Ahlenslager 1996, Johnson-Groh 1998), although Johnson-Groh has suggested that grapeferns may appear more regularly aboveground than moonworts (reported in USDA Forest Service, Eastern Region 1999).

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 reductions 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 'normal' plants may be irrelevant to *Botrychium* because of this obligate relationship (Johnson-Groh 1999).

Since there may be considerable variation in the numbers of aboveground sporophytes, best documented in moonworts, a measurement of only sporophytes may 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 20-50 gametophytes of *B. dissectum* beneath each surface square foot with a predominance of younger gametophytes versus older ones with attached sporophytes. In applying these findings to *B. mormo*, a moonwort, Casson et al. (1998) concluded 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 bad years (Johnson-Groh et al. 1998, Johnson-Groh 1999). However, events that destroy the sporophytes, may have an effect several years later (Johnson-Groh 1999). These underground stages have been compared to seed banks in angiosperms and could play an important role in population dynamics (Kalisz and McPeek 1992).

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

Many species of *Botrychium* are associated with slight to moderate disturbance regimes (Lellinger 1985, Wagner and Wagner 1993, Lesica and Ahlenslager 1996). *B. rugulosum* has been commonly found in very disturbed areas such as grazed pastures (Wagner and Wagner 1982). Within forests, the preference of *B. rugulosum* towards forest openings suggests that it may require periodic disturbance regimes that create these canopy gaps (NatureServe 2001). A species like *B. rugulosum* that often occupies open areas with a regular disturbance regime may have a metapopulation structure where local populations are founded then become extinct as succession proceeds toward a closed-canopy forest (Menges and Gawler 1986, Parsons and Browne 1982). The continued persistence of this kind of species may then depend on a regime of natural disturbances that creates a shifting mosaic of seral communities (Pickett and Thompson 1978).

POTENTIAL THREATS AND MONITORING

Threats to *B. rugulosum* include succession to closed-canopy forest, and loss or destruction of habitat (USDA Forest Service 2000). Over-zealous collecting can be significant as populations are small, but this impact is somewhat buffered by the presence of viable underground parts. Brzeskiewicz (1999) considered the biggest threat to the species to be habitat destruction through lakeshore development. She also noted that aggressive, non-native plants colonize compatible habitats and out-compete native species, especially diminutive species like *B. rugulosum*. Wagner suggested that *B. rugulosum* may be affected by warming climate as Michigan populations appeared to be declining even though nothing had apparently changed (reported in USDA Forest Service, Eastern Region 1999). A significant deterrent to effective management is the lack of information for the species.

Some of these threats will have their direct effect on the aboveground sporophyte and may be less serious, since the belowground part of the life-cycle is so important (see Sections C and F above). Simple removal of leaf tissue may be inconsequential to the ability of *Botrychium* to survive although removing sporulating individuals may eventually have an effect (Johnson-Groh 1999). Wagner and Wagner (1993) also state 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) did find 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 in moonworts has no effect on subsequent leaf size or vigor (Johnson-Groh and Farrar 1996a,b). However, grapeferns may depend more on photosynthesis than moonworts (Johnson-Groh, reported in USDA Forest Service, Eastern Region 1999). It is possible that since grapeferns are semi-evergreen, nutrients may be recycled form the old frond into the new one, and premature removal or frequent collecting may be detrimental (Johnson-Groh reported in USDA Forest Service, Eastern Region 1999). 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 wilted sporophytes of a species of *Botrychium* before sporulation. The work of Johnson-Groh (1999) also emphasized the importance of water relations to moonworts and their supporting mycorrhizae. Mycorrhizae are 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). A similar effect may occur in the open habitats often favored by *B. rugulosum*. 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). However, the disturbed sites often favored by *B. rugulosum* would likely have less organic material, and earthworm activity of cycling organic material may not be a serious threat to typical, open *B. rugulosum* habitats. It should be noted that in the Great Lakes region, *B. rugulosum* occurs with some regularity in forested environments; these habitats could be impacted by worms, so the degree of the threat is uncertain.

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 is likely an underlying necessity. Moisture relations are critical, as activities that dry the habitat may have deleterious effects on the population. Given the general preference of the species

for open sites (Wagner and Wagner 1982, Lellinger 1985, Wagner and Wagner 1993), treatments which removed portions of the canopy may be a feasible management tool. However, the caveat above regarding moisture relations should be considered. Unfortunately, no information is available on the response of *B. rugulosum* populations to management of any kind.

Since *B. rugulosum* often exists in a habitat that is early successional due to disturbance it may be prone to local extinctions. Thus population viability may rely on a shifting mosaic of suitable habitats opening for colonization (see Section F). Land protection efforts should consider the immediate area surrounding the *B. rugulosum* population to ensure that an adequate buffer to both fully protect the population from potential threats and to allow for population expansion is available (NatureServe 2001).

Brzeskiewicz (1999) noted that none of the known occurrences on Forest Service land have permanent protection status. Since ca. one third of the total known occurrences occur on National Forest land, and private sites have very limited protection (if any), long-range viability of the species may depend on Forest Service stewardship (Brzeskiewicz 1999).

RESEARCH AND MONITORING REQUIREMENTS

Like most species of *Botrychium*, *B. rugulosum* is small, inconspicuous, and difficult to find. Plants may go dormant and not appear aboveground in a given growing season (Lesica and Ahlenslager 1996). There are almost certainly undiscovered sites for *B. rugulosum*, and at a minimum, inventories for the plant should continue. While some research data have been developed about population fluctuations for certain species of *Botrychium* (Johnson-Groh 1999), specific information for *B. rugulosum* population biology is lacking. Research needs center around essentially every aspect of *B. rugulosum*. These areas include basic life history information (germination requirements, growth requirements, life span), habitat requirements, and management needs (NatureServe 2001)

Almost no information is available on *B. rugulosum* life history in relation to disturbance and colonization of new sites. While its habitat is generally considered to be open areas, it also occurs in forested habitats. Succession has been considered a threat (USDA Forest Service 2000), but it is unclear how *B. rugulosum* reacts to site changes over time. Monitoring needs include an assessment of population stability and the tracking of habitat changes through time (NatureServe 2001). Long-term monitoring programs as suggested by Ostlie (1990) and Johnson-Groh (1999) would begin to address these questions.

Basic management information such as percent canopy preference or level of competition tolerated are major needs in order to implement appropriate management programs (NatureServe 2001).

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

Exotic earthworms are a serious threat to some moonwort species, particularly *B. mormo* (Sather et al. 1998). However, it is unknown what effect, if any, exotic earthworms have on *B. rugulosum* populations or habitats.

Berlin et al. (1998) make a number of specific research and monitoring recommendations for *B. mormo*. Many of their suggestions apply to other *Botrychium* species also, and that source is recommended for detailed recommendations about *Botrychium* monitoring and research. There are also a number of specific suggestions about habitat and population monitoring for *B. rugulosum* at www.natureserve.org (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 activities. 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.

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

LITERATURE CITED AND REFERENCES

Alverson, W. S. and S. Solheim. 1981. Field survey report on endangered, threatened and rare vascular plants of the Chequamegon National Forest, WI. Contr. USDA Forest Service.

Berch, S. M. and B. Kendrick. 1982. Vesicular-arbuscular mycorrhizae of southern Ontario ferns and fern-allies. Mycologia 74: 769-776.

Berlin, N., P. Miller, J. Borovansky, U. S. Seal, and O. Byers (eds.). 1998. Population and Habitat Viability Assessment Workshop for the Goblin Fern (*Botrychium mormo*): Final Report. CBSG, Apple Valley, MN.

Bierhorst, D. W. 1958. Observations on the gametophytes of *Botrychium virginianum* and *B. dissectum*. Amer. J. of Bot. 45: 1-9.

Bower, F. O. 1926. The ferns (Filicales), volume 2. Cambridge University Press. 344 pp.

Briggs, D. and S. M. Walters. 1997. Plant variation and evolution. Cambridge University

Press. New York.

Brzeskiewicz, M. 1999. Conservation Assessment for *Botrychium rugulosum* (St. Lawrence grapefern). USDA Forest Service, Region 9.

Camacho, F. J. 1996. Mycorrhizal fungi of *Botrychium* genus communities in Montana. Unpublished proposal to the Montana Natural Heritage Program. Oregon State University, Corvallis, OR. 6 pp.

Campbell, D. H. 1911. The eusporangiate. Carnegie Inst. Wash. Publ. No. 140.

Campbell, D. H. 1922. The gametophyte and embryo of *Botrychium simplex*, Hitchcock. Annals of Botany 36:441-456.

Casson, J., J. Dobberpuhl, D. Farrar, A. Hoefferle, C. Johnson-Groh, H. Peters, H. Wagner, F. Wagner, C. Westfield, and P. Miller. 1998. Population life history and viability working group report. In: Berlin, N., P. Miller, J. Borovansky, U. S. Seal, and O. Byers (eds.). Population and Habitat Viability Assessment Workshop for the Goblin Fern (*Botrychium mormo*): Final Report. CBSG, Apple Valley, MN.

Casson, J., I. Shackleford, L. Parker, and J. Schultz. 2000. Conservation Strategy for the Goblin fern, *Botrychium mormo* W. H. Wagner. USDA Forest Service – Eastern Region 27 October, 2000 draft.

Cothrel, S. R., J. P. Vimmerstedt, and D. A. Kost. 1997. *In situ* recycling of urban deciduous litter. Soil Biol. Biochem. 29: 3/4: 295-298.

Farrar, D. R. 1998. Population genetics of moonwort populations. In: Berlin, N., P. Miller, J. Borovansky, U. S. Seal, and O. Byers (eds.). Population and Habitat Viability Assessment Workshop for the Goblin Fern (*Botrychium mormo*): Final Report. CBSG, Apple Valley, MN.

Farrar, D. R. and C. L. Johnson-Groh. 1990. Subterranean sporophytic gemmae in moonwort ferns, *Botrychium* subgenus *Botrychium.* American Journal of Botany 77: 1168-1175.

Farrar, D. R. and J. F. Wendel. 1996. On the origins and relationships of the *Botrychium matricariifolium* complex in eastern North America. (Abstract). Am. J. Botany 83(Suppl.): 125.

Foster, A. S., and E. M. Gifford. 1974. Comparative morphology of vascular plants. W. H. Freeman, San Francisco.

Gifford, E. M. and A. S. Foster. 1989. Morphology and evolution of vascular plants, third edition. W. H. Freeman and Co., New York, NY. 626 pp.

Grover, M. 2000. Rocky Road Environmental Assessment. USDA Forest Service, Superior

National Forest.
http://snf.toofarnorth.org/resources/2000/21_appen_j.htm

Hoefferle, A. M. 1999. Impacts of aerial leaf removal on leaf size of the daisy leaf moonwort (*Botrychium matricariifolium*) and the triangle moonwort (*Botrychium lanceolatum* var. *angustisegmentum*) in the subsequent year (master's thesis). Houghton, (MI): Michigan Technological University. 42 pp.

Johnson-Groh, C. 1998. Population demographics, underground ecology and phenology of *Botrychium mormo.* In: Berlin, N., P. Miller, J. Borovansky, U. S. Seal, and O. Byers (eds.). Population and Habitat Viability Assessment Workshop for the Goblin Fern (*Botrychium mormo*): Final Report. CBSG, Apple Valley, MN.

Johnson-Groh, C. 1999. Population ecology of *Botrychium* (moonworts), status report on Minnesota *Botrychium* permanent plot monitoring. Dept. of Biology, Gustavus Adolphus College, St. Peter, MN.

Johnson-Groh, C. L., D. R. Farrar. 1996a. Effects of leaf loss on moonwort ferns, *Botrychium* subgenus *Botrychium*. Am. J. Botany 83(Supple.): 127.

Johnson-Groh, C. L., D. R. Farrar. 1996b. The effects of fire on prairie moonworts (*Botrychium* subgenus *Botrychium).* Am. J. Botany 83(Supple.): 134.

Johnson-Groh, C. L., D. R. Farrar, P. Miller. 1998. [Abstract] Modeling extinction probabilities for moonwort (*Botrychium*) populations. Amer. J. Bot. Supplement 85: 95.

Kalisz, S., and M. A. McPeek. 1992. Demography of an age-structured annual: resampled projection matrices, elasticity analysis, and seed bank effects. Ecology 73: 1082–1093.

Kelly, D. 1994. Demography and conservation of *Botrychium australe,* a peculiar sparse mycorrhizal fern. N.Z. J. Bot. 32: 393-400.

Langmaid, K. K. 1964. Some effects of earthworm invasion in virgin podzols. Canadian Journal of Soil Science 44: 34-37.

Leake, J. R. 1994. The biology of myco-heterotrophic plants. New Phytologist 127: 171-216.

Lellinger, D. B. 1985. A Field Manual of the Ferns and Fern-allies of the United States and Canada. Smithsonian Institution Press, Washington D.C.

Lesica, P., and K. Ahlenslager. 1996. Demography and life history of three sympatric species of *Botrychium* subg. *Botrychium* in Waterton Lakes National Park, Alberta. Can J. Bot. 74: 538-543.

McCauley D. E., Whittier D. P., Reilly L. M. 1985. Inbreeding and the rate of self-fertilization in a grapefern, *Botrychium dissectum.* Amer. J. Bot. 72: 1978-1981.

Menges, E. S., and S. C. Gawler. 1986. Four-year changes in population size of the endemic, Furbish's lousewort: implications for endangerment and management. Natural Areas Journal 6: 6-17.

Montgomery, J. D. 1990. Survivorship and predation changes in five populations of *Botrychium dissectum* in eastern Pennsylvania. Am. Fern J. 80: 173-182.

Muller S. 1992. The impact of drought in spring on the sporulation of *Botrychium matricariifolium* (Retz) A. Br. in the Bitcherland (Northern Vosges, France). Acta. Oecol. 13:335-43.

Muller, S. 1993. Population dynamics in *Botrychium matricariifolium* in Bitcherland (Northern Vosges Mountains, France). Belg. J. Bot. 126: 13-19.

NatureServe: An online encyclopedia of life [web application]. 2001. Version 1.0. Arlington (VA): Association for Biodiversity Information. Available: http://www.natureserve.org/. (Accessed: January 21, 2001).

Nielsen, G. A. and F. D. Hole. 1963. A study of the natural processes of incorporation of organic matter into soil in the University of Wisconsin Arboretum. Wisconsin Academy of Sciences, Arts and Letters 52: 213-227.

Nielsen, G. A. and F. D. Hole. 1964. Earthworms and the development of coprogeneous A1 horizons on forest soils of Wisconsin. Soil Science Society of America Proceedings 28: 426-430.

Nixon, W. 1995. As the worm turns. American Forests. Autumn 1995: 34-36.

Ostlie W. 1990. Element Stewardship Abstract for American Ternate Grapefern. Minneapolis MN: The Nature Conservancy.

Parsons, R. F., and J. H. Browne. 1982. Causes of plant species rarity in semi-arid southern Australia. Biol. Conserv. 24: 183-192.

Peck, J. H., C. J. Peck, and D. F. Farrar. 1990. Influence of life history attributes on formation of local and distant fern populations. Am. Fern J. 80: 126-142.

Pickett, S. T. A., and J. N. Thompson. 1978. Patch dynamics and the design of nature reserves. Biol. Conserv. 13: 27-37.

Read, D. J. 1994. Plant-microbe mutualisms and community structure. In: Schulze, E.D. and H.A. Mooney (eds.) Biodiversity and ecosystem function, Springer-Verlag, New York.

Sather, N., C. Kjos, C. Mortensen, J. Gallagher, S. Mortensen, C. Leibl, B. Wolff, S. Trull, and O. Byers. Threats and Risk Working Group Report. 1998. In: Berlin, N., P. Miller, J.

Borovansky, U. S. Seal, and O. Byers (eds.). Population and Habitat Viability Assessment Workshop for the Goblin Fern *(Botrychium mormo):* Final Report. CBSG, Apple Valley, MN.

Scagel, R. F., R. J. Bandoni, G. L. Rouse, W. B. Schofield, J. R. Stein, and T. M. Taylor. 1966. An evolutionary survey of the plant kingdom. Wadsworth Publishing Co., Belmont, CA. 658 pp.

Schmid, E., and F. Oberwinkler. 1994. Light and electron microscopy of the host-fungus interaction in the achlorophyllous gametophyte of *Botrychium lunaria.* Can. J. Bot. 72: 182-188.

Soltis, D. E., and P. S. Soltis. 1986. Electrophoretic evidence for inbreeding in the fern *Botrychium virginianum* (Ophioglossaceae). Amer. J. Bot. 73: 588-592.

Tans, W. E. and D. X. Watermolen. 1997. Distribution, current population status, growth and habitat of goblin fern *(Botrychium mormo)* in Wisconsin. Wisconsin Endangered Resources Report #115. Bureau of Endangered Resources, Wisconsin Department of Natural Resources. Madison, Wisconsin.

USDA Forest Service, Eastern Region. 1999. Draft Species Data Collection Forms prepared under contract for population viability analyses on the Wisconsin and Minnesota National Forests. Unpublished reports, Eastern Region, Milwaukee, WI.

USDA Forest Service. 2000. Population Viability Assessment Database. USDA Forest Service, Eastern Region, Milwaukee, WI.

Wagner, W. H. 1959. American grapeferns resembling *Botrychium ternatum*; a preliminary report. Amer. Fern Jour. 49: 97-103.

Wagner, W. H. 1960a. Periodicity and pigmentation in *Botrychium* subg. *Sceptridium* in the northeastern United States. Bull. Torrey Bot. Club 87: 303-325

Wagner, W. H. 1960b. Evergreen grapeferns and the meanings of intraspecific categories as used in North American pteridophytes. Amer. Fern Jour. 50: 32-45.

Wagner, W. H. 1961. Some new data on the venation differences of *Botrychium dissectum* and *B. ternatum.* Amer. Fern Jour. 51: 31-33.

Wagner, W. H. 1962. Plant compactness and leaf production in *Botrychium multifidum* "ssp. *typicum*" and "forma *dentatum*". Amer. Fern Jour. 52: 1-18.

Wagner, W. H. 1991. New examples of the moonwort hybrid, *Botrychium matricariifolium* X *simplex* (Ophioglossaceae). Can. Field Nat. 105(1): 91-94.

Wagner F. S. 1993. Chromosomes of North America grapeferns and moonworts

(Ophioglossaceae: *Botrychium*). Contr. Univ. Michigan Herb. 19: 83-92.

Wagner, W. H. 1998. A Background for the Study of Moonworts. In: Berlin, N., P. Miller, J. Borovansky, U.S. Seal, and O. Byers (eds.). Population and Habitat Viability Assessment Workshop for the Goblin Fern *(Botrychium mormo):* Final Report. CBSG, Apple Valley, MN.

Wagner, W. H., and A. R. Smith. 1993. In: Flora of North America North of Mexico, Volume 1. Flora of North America Editorial Committee (ed.). Oxford University Press. New York.

Wagner, W. H., and F. S. Wagner. 1981. New species of moonworts, *Botrychium* subg. *Botrychium* (Ophioglossaceae), from North America. American Fern Journal 71(l): 26.

Wagner, W. H., and F. S. Wagner. 1982. *Botrychium rugulosum* (Ophioglossaceae), a newly recognized species of evergreen grapefern in the Great Lakes area of North America. Contr. Univ. Mich. Herb. 15: 315-324.

Wagner, W. H., and E. S. Wagner. 1983. Genus communities as a systematic tool in the study of new world *Botrychium* (Ophioglossaceae). Taxon 32(1): 51-63.

Wagner, W. H. and F. S. Wagner. 1993. Ophioglossaceae. In: Flora of North America, Vol. 2, Flora of North America Editorial Committee (ed.). Oxford University Press, NY.

Wagner, W. H., F. S. Wagner, and J. M. Beitel. 1985. Evidence for interspecific hybridization in pteridophytes with subterranean mycoparasitic gametophytes. Proc. Royal Soc. of Edin. 86B: 273-281.

Walton, G. B. 1999. Draft literature review: *Botrychium rugulosum*. U. S. Forest Service Region 9.

Wherry, E. T. 1995. The Fern Guide: Northeasern and Midland United States and Adjacent Canada. Dover Publications, Inc., NY.

Whittier, D. P. 1972. Gametophytes of *Botrychium dissectum* as grown in sterile culture. Botanical Gazette 133: 336-339.

Whittier, D. P. 1973. The effects of light and other factors on spore germination in *Botrychium dissectum*. Canadian Journal of Botany 51: 1791-1794.

Whittier, D. P. 1996. [Abstract] Delayed gametophyte growth in *Botrychium*. Am. J. Bot. 83(Suppl.):133.

Whittier, D. P. 2000. [Abstract] Gametophyte and young sporophyte development in the Ophioglossaceae. Am. J. Bot. (Suppl.)

Zika, P. F. 1992. Draft management guide for rare *Botrychium* species (moonworts and grapeferns) for the Mount Hood National Forest. Unpublished report. Oregon Natural Heritage Program, Portland, OR. 43 pp. plus appendices.

Zika, P. F. 1994. A draft management plan for the moonworts *Botrychium ascendens, B. crenulatum, B. paradoxum,* and *B. pedunculosum* in the Wallowa-Whitman, Umatilla, and Ochoco National Forests. Unpublished report. Oregon Natural Heritage Program, Portland, OR. 41 pages plus figures, tables, and appendices.

Natural Heritage Program Databases consulted and queried

UNITED STATES

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

CANADA

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

APPENDICES

APPENDIX A – ELEMENT OCCURRENCE RECORDS, *BOTRYCHIUM RUGULOSUM*

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 1
Minnesota 31
Wisconsin 14

MICHIGAN

Location: Michigan, Delta County
Ownership: Hiawatha National Forest
Abundance: 12 plants
Habitat: Plants growing in low, wet spot in jack pine barrens, on sandy outwash plain. Site has thick mounds of moss. Associated species include *Malaxis unifolia, Botrychium dissectum, B. multifidum, B. matricariifolium, Cypripedium acaule.*
Comments: 1995
Source of information: Michigan Natural Features Inventory Element Occurrence Record

MINNESOTA

Location: Minnesota, Aitkin County
Ownership: Unknown
Abundance: 7 plants
Habitat: Plants growing in thick mounds of moss. Brush-free, mossy natural stand of *Pinus banksiana*. In sandy, peat soil. Associated with *Malaxis unifolia, Botrychium dissectum, B. multifidum, B. matricariifolium, Cypripedium acaule.*
Comments: 1991
Source of information: Minnesota Natural Heritage Program Element Occurrence Record

Location: Minnesota, Aitkin County
Ownership: Unknown
Abundance: not listed
Habitat: Observed in only a few areas of moss. Plants occur in an upland stand of *Pinus banksiana*. Associated with *Botrychium multifidum, B. dissectum, Malaxis unifolia, Goodyera repens*. Growing in mossy areas of stand.

Location: Minnesota, Aitkin County
Ownership: Private
Abundance: not listed

Habitat: Mixed hardwood forest with *Acer saccharum* and *Pinus banksiana*. Associated with *Quercus alba, Sanicula marilandica, Gaultheria procumbens*.
Comments: 1991
Source of information: Minnesota Natural Heritage Program Element Occurrence Record

Location: Minnesota, Aitkin County
Ownership: Private
Abundance: not listed
Habitat: Natural stand of *Pinus banksiana*. Plants growing in sandy loam. Associated with *Botrychium multifidum, Chimaphila umbellata, Gaultheria procumbens*.
Comments: 1991
Source of information: Minnesota Natural Heritage Program Element Occurrence Record

Location: Minnesota, Aitkin County
Ownership: Unknown
Abundance: not listed
Habitat: Plants occur in a pine plantation. Associated with *Botrychium multifidum, Monotropa hypopithys, Pyrola chlorantha, Moneses uniflora, Cypripedium acaule*.
Comments: 1997
Source of information: Minnesota Natural Heritage Program Element Occurrence Record

Location: Minnesota, Aitkin County
Ownership: State
Abundance: not listed
Habitat: Small, lush herbaceous/ shrub opening along old woods rd. Surrounding forest of mixed hardwoods with *Populus grandidentata, P. trmuloides, Quercus rubra,* and several large *Pinus strobus*. Associated species: *Polytrichum* sp., *Fragaria, Trifolium, B. multifidum, B. dissectum* and *(*var. *dissectum* and var. *obliquum)* and *Ophioglossum pusillum*. Also present: *Diervilla lonicera, Pyrola ellipitica* and *Solidago canadensis.* Shrubs: *Salix* spp., *Betula papyrifera* and *Populus balsamifera.*
Comments: 1997
Source of information: Minnesota Natural Heritage Program Element Occurrence Record

Location: Minnesota, Aitkin County
Ownership: Unknown
Abundance: not listed
Habitat: At the edge of an old gravel pit under young *Populus* with *Rubus* and *Fragaria.*
Comments: 1997
Source of information: Minnesota Natural Heritage Program Element Occurrence Record

Location: Minnesota, Carlton County
Ownership: Private
Abundance: 1 plant
Habitat: located in brushy field near edge of encroaching fir and spruce woods. Associated spp. include *Vaccinium angustifolium, Pteridium aquilinum, Danthonia spicata, Schizachne purpurescens, Fragaria virginiana* and *Solidago nemoralis.*

Comments: 1997
Source of information: Minnesota Natural Heritage Program Element Occurrence Record

Location: Minnesota, Cass County
Ownership: USFS
Abundance: Not listed
Habitat: Plants occur in a mossy, upland stand dominated by *Pinus banksiana* and *Pinus resinosa*. Associated species include: *Thalictrum dioicum, Pyrola secunda, anemone quinquefolia, Botrychium virginianum, Botrychium multifidum, Goodyera tesselata,* and *Liparis loeselii.*
Comments: 1992
Source of information: Minnesota Natural Heritage Program Element Occurrence Record

Location: Minnesota, Cass County
Ownership: Native American land
Abundance: Not listed
Habitat: Plant observed on a small mound on the edge of a small low area in a second-growth deciduous forest dominated by *Acer saccharum* and *Tilia americana*. This forest occurs on a plateau above steep south shore of the lake. Associated spp include: *Uvularia grandiflora, Sanguinaria canadensis, Monotropa hypopithys, Botrychium minganense, B. multifidum* and *B. virginianum.*
Comments: 1992
Source of information: Minnesota Natural Heritage Program Element Occurrence Record

Location: Minnesota, Cass County
Ownership: County
Abundance: Not listed
Habitat: Plants occur in moss surrounding several large white spruce, and extend into somewhat open, grassy area of sumac, aspen, maple, red pine and jack pine. Associated species include: *Rhus radicans, Galium triflorum, Botrychium multifidum* and *B.dissectum* var. *obliquum.*
Comments: 1992
Source of information: Minnesota Natural Heritage Program Element Occurrence Record

Location: Minnesota, Cass County
Ownership: Private
Abundance: Not listed
Habitat: 3 species of *Botrychium* subgenus *Sceptridium* observed at this Location: *B. multifidum, B. rugulosum* and *B. oneidense*. Area of small rises and shallow, level low areas with *Fraxinus nigra, Populus tremuloides, Acer saccharum,* and *Tilia americana.*
Comments: 1992
Source of information: Minnesota Natural Heritage Program Element Occurrence Record

Location: Minnesota, Cass County
Ownership: Private
Abundance: Not listed

Habitat: Plants occur in a mossy, sloping stand of *Pinus banksiana*. Associated species include: *Epigaea repens, Agastache foeniculum, Aster macrophyllus, Quercus macrocarpa,* and *Botrychium multifidum.*
Comments: 1992
Source of information: Minnesota Natural Heritage Program Element Occurrence Record

Location: Minnesota, Cass County
Ownership: USFS
Abundance: 50-100 plants
Habitat: Plants found in transition zone between red pine plantation and bordering wetland, growing on w-facing gentle slope in slightly moist soil. *Botrychium multifidum* also found at site.
Comments: 1997
Source of information: Minnesota Natural Heritage Program Element Occurrence Record

Location: Minnesota, Cass County
Ownership: USFS
Abundance: 25+ plants
Habitat: Growing in wetland drainage with red pine mixed with aspen, ash and elm. Groundcover dominated by *Rubus* spp. and *Botrychium multifidum* (100's of plants). Other Associated spp include *Botrychium dissectum* var. *dissectum* and *obliquum, Poa* spp., sedge spp., wild strawberry, ostrich and interrupted ferns.
Comments: 1997
Source of information: Minnesota Natural Heritage Program Element Occurrence Record

Location: Minnesota, Cook County
Ownership: USFS
Abundance: 4 plants
Habitat: In open field (old log landing). Associated spp.: *Danthonia spicata, Fragaria virginiana, Anaphalis margaritacea, Schizachne purpurescens, Oryzopsis asperifolia, Antennaria neglecta, Botrychium dissectum* var. *obliquum, B. matricariifolium, Botrychium* sp. (identity uncertain), *B. multifidum.*
Comments: 1997
Source of information: Minnesota Natural Heritage Program Element Occurrence Record

Location: Minnesota, Cook County
Ownership: USFS
Abundance: 5 plants
Habitat: On trail edge in young red pine plantation. Associated spp.: *Fragaria virginiana, Anaphalis margaritacea, Diervilla lonicera, Aster macrophyllus, Taraxacum officinale, Lycopodium clavatum, Botrychium dissectum.*
Comments: 1997
Source of information: Minnesota Natural Heritage Program Element Occurrence Record

Location: Minnesota, Cook County
Ownership: USFS

Abundance: 1 sterile plant
Habitat: Very old log landing site. Sparse vegetation in some places. *Poa sp, Anaphalis margaritacea, Apocynum androsaemifolium. Fragaria virginiana, aster ciliolatus, A. macrophyllus, Lactuca* sp., *Rubus strigosus, Epilobium angustifolium, Botrychium multifidum, B. matricariifolium.*
Comments: 1997
Source of information: Minnesota Natural Heritage Program Element Occurrence Record

Location: Minnesota, Itasca County
Ownership: Unknown
Abundance: Infrequent.
Habitat: Plants occur along a mossy, grassy road through a forest dominated by *Pinus banksiana*. Associated with *Aster macrophyllus, Anaphalis margaritacea, Botrychium multifidum, Fragaria vesca, Pteridium aquilinum.*
Comments: 1994
Source of information: Minnesota Natural Heritage Program Element Occurrence Record

Location: Minnesota, Itasca County
Ownership: Unknown
Abundance: Not listed
Habitat: In a dried tailings pond under small *Populus* and *Betula*. Associated with *Pyrola elliptica, Solidago nemoralis, S. canadensis, Castilleja coccinea.*
Comments: 1998
Source of information: Minnesota Natural Heritage Program Element Occurrence Record

Location: Minnesota, Lake County
Ownership: USFS
Abundance: <10 plants in scattered singles
Habitat: Plants growing in areas of shorter grasses in full sun and under small pine clump in clearing. Area currently used as a camp site and historically used as a log landing and/or home site. Associated species: *Trifolium* spp., *Achillea millefolium*, short grasses, *Botrychium simplex, B. matricariifolium, B. minganense, B. multifidum, B. dissectum and B. hesperium.*
Comments: 1993
Source of information: Minnesota Natural Heritage Program Element Occurrence Record

Location: Minnesota, Lake County
Ownership: USFS
Abundance: At least 18 fronds
Habitat: A grassy clearing. Associated spp: *Danthonia spicata, Fragaria virginiana, Solidago canadense, Aster ciliolatus, Anaphalis margaritacea, Phleum pratense, Agrostis stolonifera, Botrychium multifidum, B. dissectum* var. *dissectum, B. dissectum* var. *obliquum*. Old heliport site.
Comments: 1997
Source of information: Minnesota Natural Heritage Program Element Occurrence Record

Location: Minnesota, Lake County
Ownership: USFS
Abundance: 1 plant with sporophore
Habitat: In moss over broken rock fragments in what used to be a trail. Opening in fairly open mixed pine stand with cedar and quaking aspen. Associated spp: *Fragaria virginiana, Aster macrophyllus, Antennaria neglecta, Viola conspersa, Agrostis* spp., *Carex tenera, Calamagrostis canadensis, Diervilla lonicera, Oryzopsis asperifolia, Solidago nemoralis, Salix humilis, Anaphalis margaritacea, Arctostaphylos uva-ursi.*
Comments: 1997
Source of information: Minnesota Natural Heritage Program Element Occurrence Record

Location: Minnesota, Lake County
Ownership: Unknown
Abundance: Not listed
Habitat: Old "wildlife" opening with *Pinus strobus, P. resinosa, saplings* and *Fragaria virginiana, Oryzopsis asperifolia, Danthonia spicata, Rubus strigosus, Botrychium dissectum* var. *dissectum, B. Dissectum* var. *obliquum, B. multifidum.*
Comments: 1999
Source of information: Minnesota Natural Heritage Program Element Occurrence Record

Location: Minnesota, Pine County
Ownership: Private
Abundance: Not listed
Habitat: Plants growing in a mossy, upland stand of *Pinus banksiana*. Trees are mature and fairly widely spaced. Plants most concentrated in several mossy areas with *Botrychium multifidum, B. matricariifolium, B. dissectum* var. *dissectum, and B. dissectum* var. *obliquum.*
Comments: 1993
Source of information: Minnesota Natural Heritage Program Element Occurrence Record

Location: Minnesota, Pine County
Ownership: State
Abundance: Not listed
Habitat: Plants occur in a small opening adjacent to a white pine plantation under *Rubus,* and *Acer* and *Quercus* seedlings. Associated species include *Botrychium dissectum* var. *obliquum, Comptonia peregrina, Pteridium aquilinum,* and *Campanula rotundifolia.*
Comments: 1993
Source of information: Minnesota Natural Heritage Program Element Occurrence Record

Location: Minnesota, Pine County
Ownership: Private
Abundance: Numerous
Habitat: Plants occur in the sloping, mossy transitional area between a red pine plantation and grassy low area. A substantial population of *Botrychium* (*virginianum, multifidum, matricariifolium* and both varieties of *B. dissectum*) of relatively small size but many with fertile fronds. Numerous specimens of *B. rugulosum* present, with *Viola adunca, Matteuccia struthiopteris, Athyrium filix-femina, Malaxis unifolia,* and *Pteridium aquilinum.*

Comments: 1993
Source of information: Minnesota Natural Heritage Program Element Occurrence Record

Location: Minnesota, Pine County
Ownership: State
Abundance: Not listed
Habitat: Plants occur in a mossy upland stand of *Pinus banksiana* with *Corylus americana, Comptonia peregrina, Spiranthes lacera, Melampyrum lineare,* and both varieties of *Botrychium dissectum.*
Comments: 1993
Source of information: Minnesota Natural Heritage Program Element Occurrence Record

Location: Minnesota, Pine County
Ownership: Private
Abundance: Not listed
Habitat: Plants occur along the edge of a low area in a deciduous forest with *Quercus rubra, Fraxinus nigra,* and *Larix laricina.* Associated species include: *Athyrium filix-femina, Streptopus roseus, Lycopus uniflorus, Cicuta maculata, Onoclea sensibilis, and Ophioglossum pusillum. Botrychium dissectum* var. *dissectum, B. dissectum* var. *obliquum,* and *B. multifidum* also present at this site.
Comments: 1993
Source of information: Minnesota Natural Heritage Program Element Occurrence Record

Location: Minnesota, Pine County
Ownership: State
Abundance: Occasional
Habitat: Plants in prairie openings amid open grown bur oaks and n pin oak. On island in St. Croix river. On level crest of basalt ridge at center of island. High quality prairie with soil 2-20 cm to bedrock; silt with some small pebbles. Dark A horizon to 10 cm. Associates include *Schizachyrium, Bromus kalmii, Asclepias tuberosus, Liatris aspera, Antennaria neglecta, Solidago nemoralis.*
Comments: 1997
Source of information: Minnesota Natural Heritage Program Element Occurrence Record

Location: Minnesota, Sherburne County
Ownership: USFWS
Abundance: Not listed
Habitat: On edge of sedge-mat near trees.
Comments: 1978
Source of information: Minnesota Natural Heritage Program Element Occurrence Record

Location: Minnesota, Washington County
Ownership: State
Abundance: Not listed
Habitat: Steep n-facing hillside
Comments: 1995

Source of information: Minnesota Natural Heritage Program Element Occurrence Record

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Location: Wisconsin, Bayfield County
Ownership: One of the four sites is privately owned, the others are Forest Service ownership
Abundance: 1980: About 60 plants at four sites in the same locality 1991: 8 – 10 plants found in one area, no plants found in 6 other 1980 sites in this area.
Habitat: Sandy lakeshore dominated by *Calamagrostis canadensis* and *Solidago altissima* with *B. multifidum*, *B. dissectum*, and *B. matricariifolium.*
Comments: Many of these plants have been re-identified as *B. multifidum.*
Source of information: Wisconsin Natural Heritage Program Element Occurrence Record

Location: Wisconsin, Bayfield County
Ownership: Forest Service
Abundance: 1980: Not listed 1991: See note in above record
Habitat: Sandy soil under *Populus* trees
Comments: This occurrence is near the above listed location but away from the lakeshore. Many of the plants in this locality have been re-identified as *B. multifidum.*
Source of information: Wisconsin Natural Heritage Program Element Occurrence Record

Location: Wisconsin, Bayfield County
Ownership: Forest Service
Abundance: 1999: 5 rosettes around two lakes 1981: 2 specimens
Habitat: 1999: Upper slopes surrounding seepage ponds with fluctuating water levels. Plants were found in a mostly open area on sandy soil with S and NE aspects. *Calamagrostis canadensis* and sedge meadow surrounding ponds with *Pinus banksiana, Pteridium aquilinum, B. multifidum,* and *B. dissectum*. 1981: Moist area around a sandy pond with *Spiraea alba, Solidago graminifolia, Lycopus americanus, Erigeron strigosus, Potentilla anserina, Geum canadense, Stachys palustris, Achillea millefolium, Fragaria virginiana*.
Source of information: Wisconsin Natural Heritage Program Element Occurrence Record

Location: Wisconsin, Bayfield County
Ownership: Forest Service
Abundance: 1991: 13 plants
Habitat: Listed as “at road intersection”
Comments: Not confirmed as species as of March 1992
Source of information: Wisconsin Natural Heritage Program Element Occurrence Record

Location: Wisconsin, Bayfield County
Ownership: Forest Service
Abundance: 1991: 50 – 70 plants found at this site with about 100 other plants in the general area. 1980: 30 plants
Habitat: 1980: In and around moist depression with *B. multifidum, B. dissectum,* var. *dissectum* and var. *obliquum.*
Comments: Plants less common in surrounding dense jack pine.

Source of information: Wisconsin Natural Heritage Program Element Occurrence Record

Location: Wisconsin, Bayfield County
Ownership: Forest Service
Abundance: Seven sites, four of which were visited. Population sizes ranged from 4 to 50 plants (1992). Small numbers of this species found in scattered locations. 15 – 20 other sites surveyed (1991). Total of 25 plants seen (1991).
Habitat: Found in an "open brush prairie" with sedges, grasses, sweet fern, blueberry, and aspen saplings at one site. Generally semi-open, dry, sandy areas.
Comments: Some of this area was scheduled for burning in 1993. Boundary drawn around four sites where species were found in 1991. There are other element occurrence locations for this species nearby. Species not confirmed at most of the sites as of March 1992.
Source of information: Wisconsin Natural Heritage Program Element Occurrence Record

Location: Wisconsin, Bayfield County
Ownership: Forest Service
Abundance: 1992: 18 – 20 stems (80% in flower, 20% mature, non-flowering)
Habitat: Approximately 15-year old aspen/fir stand on dry sandy soil with bracken fern, sweet fern, blackberries. Other *Botrychium* present include *B. dissectum* (both varieties), *B. multifidum*, and B. *matricariifolium*. WSW exposure, 0-1% slope, fairly open. Population is on, and along, an ungraded woods road, also extending into the aspen.
Comments: Probably more plants in the area than were located during this brief visit.
Source of information: Wisconsin Natural Heritage Program Element Occurrence Record

Location: Wisconsin, Bayfield County
Ownership: Forest Service
Abundance: 1992: 13 plants (80% in flower, 20% mature, non-flowering)
Habitat: Frost pocket with bracken fern, sweet fern, Indian paintbrush, large scattered red and white pine with young aspen. Slopes above pocket are resprouting aspen after clearcut. E exposure, sandy dry soils, 0-2% slope.
Comments:
Source of information: Wisconsin Natural Heritage Program Element Occurrence Record

Location: Wisconsin, Bayfield County
Ownership: Forest Service
Abundance: 8/29/1992 - 7 plants (20% in flower, 70% mature, non-flowering, 10% seedlings). 8/30/1992 - 2 flowering and 2 non-flowering plants.
Habitat: Red pine, jack pine, and aspen. Fairly open pond edge with grasses, bracken fern, and blueberry. S exposure, mostly open with well-drained loamy sand to sandy soils.
Comments:
Source of information: Wisconsin Natural Heritage Program Element Occurrence Record

Location: Wisconsin, Bayfield County
Ownership: Forest Service
Abundance: 1992: 1 flowering and 2 non-flowering plants
Habitat: Ecotone between upland aspen and open sedge meadow associated with a small

pond. Plants just under a hazelnut canopy. *B. dissectum* is also at this site. ESE exposure, < 5% slope, moderate light and moisture levels, loamy sand
Comments:
Source of information: Wisconsin Natural Heritage Program Element Occurrence Record

Location: Wisconsin, Bayfield County
Ownership: Forest Service
Abundance: 1993: over 50 plants, all flowering
Habitat: Lake shore meadow dominated by *Calamagrostis canadensis*. Also present were over 10 *Ophioglossum vulgatum*.
Comments:
Source of information: Wisconsin Natural Heritage Program Element Occurrence Record

Location: Wisconsin, Douglas County
Ownership: Not listed
Abundance: Not listed
Habitat: Sandy lakeshore
Comments: Last observation was 1938
Source of information: Wisconsin Natural Heritage Program Element Occurrence Record

Location: Wisconsin, Forest County
Ownership: Forest Service
Abundance: 1992: Less than 50 plants scattered throughout the area
Habitat: Grassy, open field with few trees. Large patches of barren strawberry (*Waldsteinia fragarioides*) cover the field.
Comments: Appears to have been an old Civilian Conservation Corps site.
Source of information: Wisconsin Natural Heritage Program Element Occurrence Record

Location: Wisconsin, Marinette County
Ownership: Not listed
Abundance: 1980: Not listed
Habitat: Dry sandy soil near edge of *Pinus resinosa* plantation on a previously abandoned field with *Hieracium aurantiacum* and grasses.
Source of information: Wisconsin Natural Heritage Program Element Occurrence Record

APPENDIX B. *BOTRYCHIUM* STATUS AND THREATS SUMMARY

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

Table 1. *Botrychium* status.

	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 Status:
E = state endangered

	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. spathulatum	(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

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.

Key

- range: wide (occurs across much of North America), narrow (e.g. Lake States), endemic (restricted to Lake States), disjunct (separated from main population).
- amplitude: broad (tolerates a variety of habitats and conditions), intermediate, narrow (very specific requirements).
- estimated population trend: increasing, stable, decreasing, unknown (insufficient information to estimate trend).
- habitat integrity: good (most habitats/sites protected, not commonly impacted by management), fair, poor (most sites degraded, unoccupied habitat subject to numerous impacts), unknown.
- vulnerability: high (populations generally not resilient or are intolerant of habitat changes), medium, low (populations resilient and/or resistant to change), unknown.

Table 3. Major threats to *Botrychium*.

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

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

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

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

Global, National, and Subnational Conservation Status Ranks

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

What the Ranks Mean

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

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

Species known in an area only from historical records are ranked as either H (possibly extirpated/possibly extinct) or X (presumed extirpated/presumed extinct). Other codes, rank variants, and qualifiers are also allowed in order to add information about the element or

indicate uncertainty. See the lists of conservation status rank definitions for complete descriptions of ranks and qualifiers.

Rank Definitions

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

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

Assessment Criteria

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

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

For species elements, the following factors are considered in assigning a rank:
total number and condition of occurrences
population size
range extent and area of occupancy
short- and long-term trends in the foregoing factors
threats
fragility.

Secondary factors include the geographic range over which the element occurs, threats to

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

Global Heritage Status Rank Definitions

Rank	Definition
GX	Presumed Extinct—Believed to be extinct throughout its range. Not located despite intensive searches of historical sites and other appropriate habitat, and virtually no likelihood that it will be rediscovered.
GH	Possibly Extinct (species)—Known from only historical occurrences, but may nevertheless still be extant; further searching needed.
G1	Critically Imperiled—Critically imperiled globally because of extreme rarity or because of some factor(s) making it especially vulnerable to extinction. Typically 5 or fewer occurrences or very few remaining individuals (<1,000).
G2	Imperiled—Imperiled globally because of rarity or because of some factor(s) making it very vulnerable to extinction or elimination. Typically 6 to 20 occurrences or few remaining individuals (1,000 to 3,000).
G3	Vulnerable—Vulnerable globally either because very rare and local throughout its range, found only in a restricted range (even if abundant at some locations), or because of other factors making it vulnerable to extinction or elimination. Typically 21 to 100 occurrences or between 3,000 and 10,000 individuals.
G4	Apparently Secure—Uncommon but not rare (although it may be rare in parts of its range, particularly on the periphery), and usually widespread. Apparently not vulnerable in most of its range, but possibly cause for long-term concern. Typically more than 100 occurrences and more than 10,000 individuals.
G5	Secure—Common, widespread, and abundant (although it may be rare in parts of its range, particularly on the periphery). Not vulnerable in most of its range. Typically with considerably more than 100 occurrences and more than 10,000 individuals.

National (N) and Subnational* (S) Heritage Status Rank Definitions

* Subnational indicates jurisdictions at the state or provincial level (e.g. California, Ontario).

Rank	Definition
NX SX	Presumed Extirpated—Element is believed to be extirpated from the nation or subnation*. Not located despite intensive searches of historical sites and other appropriate habitat, and virtually no likelihood that it will be rediscovered.
NH SH	Possibly Extirpated (Historical)—Element occurred historically in the nation or subnation*, and there is some expectation that it may be rediscovered. Its presence may not have been verified in the past 20 years. An element would become NH or SH without such a 20-year delay if the only known occurrences in a nation or subnation were destroyed or if it had been extensively and unsuccessfully looked for. Upon verification of an extant occurrence, NH or SH-ranked elements would typically receive an N1 or S1 rank. The NH or SH rank should be reserved for elements for which some effort has been made to relocate occurrences, rather than simply using this rank for all elements not known from verified extant occurrences.
N1 S1	Critically Imperiled—Critically imperiled in the nation or subnation* because of extreme rarity or because of some factor(s) making it especially vulnerable to extirpation from the subnation. Typically 5 or fewer occurrences or very few remaining individuals (<1,000).
N2 S2	Imperiled—Imperiled in the nation or subnation* because of rarity or because of some factor(s) making it very vulnerable to extirpation from the nation or subnation. Typically 6 to 20 occurrences or few remaining individuals (1,000 to 3,000).
N3 S3	Vulnerable—Vulnerable in the nation or subnation* either because rare and uncommon, or found only in a restricted range (even if abundant at some locations), or because of other factors making it vulnerable to extirpation. Typically 21 to 100 occurrences or between 3,000 and 10,000 individuals.
N4 S4	Apparently Secure—Uncommon but not rare, and usually widespread in the nation or subnation*. Possible cause of long-term concern. Usually more than 100 occurrences and more than 10,000 individuals.
N5 S5	Secure—Common, widespread, and abundant in the nation or subnation*. Essentially ineradicable under present conditions. Typically with considerably more than 100 occurrences and more than 10,000 individuals.
N? S?	Unranked—Nation or subnation* rank not yet assessed.

APPENDIX D. CONTRACTOR QUALIFICATIONS AND EXPERIENCE

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

Contact Information

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

Recent Experience

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

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

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

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

Education

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

Publications

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

Missoula, MT. 66 p. plus appendices.
Rabe, Fred, and Steve Chadde. 1994. Classification of Aquatic and Semiaquatic Wetland Natural Areas in Idaho and Western Montana. Natural Areas Journal 14(3): 175-187.
Statement of Qualifications – Dr. Greg Kudray

Recent Experience

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

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

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

EDUCATION

Michigan Technological University, Houghton, Michigan. Ph.D. in Wetland Ecology. 1999. Research project involved the development of a ecosystem classification system for the

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

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

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